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Survival of 534 incisors after intra-alveolar root fracture in patients aged 7–17 years

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Abstract – The purpose of the study was to evaluate and assess the survival rate of 534 root fractured teeth, including factors that may affect the survival rate but were not included in previous long-term studies. Location of fracture was registered as in the cervical, cervical/middle, middle and apical one-third of the root, and root development was categorized into five stages. Altogether, 383 (78%) showed healing of the fracture, with either formation of hard tissue or interposition of soft tissue between the fragments. In these teeth, no significant difference was found between positions in the root or types of healing. In 325 teeth, the healing remained unchanged throughout the control period, while 58 teeth showed a posthealing complication. A new injury occurred in 47 teeth; in 21 of these, the injury healed spontaneously, in four after endodontic treatment. Increased mobility of the coronal fragment was recorded for 32 teeth, and in 11 of these, the looseness of the fragment was so pronounced that the teeth had to be extracted. No healing, i.e. radiolucency in the alveolar bone, adjacent to fracture, took place in 109 teeth (22%). Of these teeth, 34 were extracted during the observation time while 75 (69%) showed healing after endodontic therapy. At the final assessment of survival (including all parameters) of 534 root fractured teeth, 425 (80%) showed survival and 109 (20%) were extracted during the observation period. It was concluded that the survival of root-fractured teeth was high for up to10 years of observation (mean = 63 months). The highest frequency of tooth loss (70%) was found in 77 teeth with horizontal fractures restricted to the cervical part of the root. When these teeth were excluded, the frequency of survival in remaining teeth rose to 88%.

In previous studies of intra-alveolar root fractures attention was mainly focused on the frequency and types of healing, and its relation to clinical and treatment parameters, while other parameters that may affect the frequency of survival rates were not assessed (1–15). Therefore, a comprehensive long-term study, taking into account factors such as immediate extraction of the severely injured teeth, occurrence of a new injury, posthealing complications, outcome of endodontic treatment of non-healed teeth and extraction of teeth for excessive looseness of coronal fragment, appears desirable.

In two previous studies, an attempt was made to clarify the reasons for the frequent loss of teeth with horizontal fracture in the cervical part of the root (11, 14). It was suggested that the main reason could be a combination of fracture position and healing by interposition of soft tissue between the fragments. These two factors together seem to decrease the resistance of the coronal fragment to absorb new impacts or even to allow normal function, resulting in a loose coronal fragment and loss of the tooth (11). One can thus speculate whether teeth with fractures in the middle or apical part of the root are more resistant to a new impact and are therefore less frequently newly luxated, compared to teeth with a cervical fracture. Furthermore, it is not known whether the occurrence of a new luxation in these teeth is related to the type of fracture healing, i.e. healing with hard tissue (fusion) or healing with interposition of soft tissue between the fragments.

Obliteration of the pulpal lumen by formation of hard tissue has also been considered a posthealing complication after a root fracture (16). Although necrosis of the pulp and periradicular inflammation has so far not been reported as a sequel to the pulp obliteration in root-fractured teeth, in contrast to merely luxated teeth (17). This phenomenon needs to be investigated in a more extensive clinical material.

The purpose of the present study was therefore, in a large material of root-fractured teeth, to perform a survival analysis of the following parameters: (i) long-term survival and its relation to healing types, (ii) location of fracture in the root and stage of root development, (iii) outcome of endodontic treatment in teeth primarily showing no fracture healing, (iv) consequences of a new injury and (v) frequency of looseness of the coronal fragment requiring extraction of the tooth.

Material and methods

The present study includes all teeth with an intra-alveolar root fracture treated at the Department of Paediatric Dentistry, Eastman Institute in Stockholm, between 1959 and 1995. Parts of this material have previously been reported (10–13). The study does not include cases in which the coronal fragment was lost at the time of injury, teeth that were initially treated at another clinic and then referred to the Eastman Institute for further therapy and teeth with intra-alveolar root fractures that occurred after endodontic treatment of mostly immature incisors (18).

A total of 585 teeth with an intra-alveolar root fracture were received for treatment. Thirteen with avulsed and then replanted coronal fragments and 38 that could be followed for less than 12 months were excluded. This left 534 teeth for evaluation, which are presented with respect to stage of root development and type of healing in Table 1.

For various reasons, 42 of these teeth were extracted at the first examination, 27 with the fracture in the cervical, 2 in the cervical mid-root part and 13 in middle part of the root (Fig. 1). These teeth were excluded from the follow-up series of controlled teeth but included in the final survival assessment of root-fractured teeth. This limitation left 492 controlled teeth, 461 maxillary and 31 mandibular incisors, from 432 patients (288 boys and 144 girls) aged 7–17 years (mean age = 11.4 years).

The postinjury control intervals were irregular and varied from 6 to 12 months. In the case of a new luxation of the coronal fragment, the follow up was measured from initial injury to the last control. Accordingly, the follow up ended if the tooth was extracted after a new trauma, unsuccessful endodontic treatment or due to the loosening of the coronal fragment. In 45 teeth for which the exact date of primary injury was insecure or unknown, the follow up started from the date of fracture disclosure.

Patient records were examined with respect to the clinical dates at first and, when present, secondary luxation. Radiographs taken at the time of injury were evaluated with respect to the position of fracture in the root and the stage of root development. The control radiographs were evaluated with respect to the occurrence and type of fracture healing, formation of hard tissue in the pulpal lumen, occurrence of radiolucency in periradicular bone adjacent to fracture, the outcome of endodontic treatment and occurrence of a secondary luxation of the coronal fragment.

Table 1. Distribution of 534 teeth with intra-alveolar root fracture with respect to the position of the fracture in one-third of the root: C (cervical), CM (cervical and middle), M (middle) and A (apical part of the root), and the stage of root development: 1, 2 and 3 (less than one-third, one-half and two-thirds of the root length respectively), 4 (almost completed root length, open apical foramen) and 5 (completed root development, narrow apical foramen)

Stage of root development	Position in the root				
	C	CM	M	A	Total
1	3		1		4
2	10		14	5	29
3	4	1	16	10	31
4	13	7	38	19	77
5	45	39	185	79	348
Not known	2		31	12	45
Total	77	47	285	125	534

The teeth in root development stages 1–4 are considered immature and the teeth in stage 5 mature (immature teeth = 25.4% and mature = 74.5%).

Stage of root development

The stage of root development was estimated from the length of the root and the width of the apical foramen and assigned to one of five groups as suggested by Cvek et al. (10). Teeth with a wide and divergent apical foramen and root length estimated as less than one-third, one-half and two-thirds of the final root length were assigned to groups 1, 2 and 3 respectively. Teeth with an almost complete root end but an open apical foramen were assigned to group 4 and teeth with completed root development and a narrow apical foramen to group 5. Teeth in groups 1–4 were considered *immature* and teeth in group 5 *mature*.

Position of fracture

With regard to the position of the fracture in the root, teeth were divided into four groups: C, CM, M and A, as suggested by Cvek et al. (11). Teeth with a horizontal fracture restricted to the cervical one-third of the root were assigned to group C. Teeth with oblique fractures involving both cervical and middle parts of the root were assigned to group CM and teeth with fractures in the middle or apical one-third of the root were assigned to groups M and A respectively.

Type of healing

Teeth showing healing of the fracture were, according to their appearance in radiographs, assigned into five groups of fracture healing: H, Ha, HS and S, according to Andreasen and Hjørting-Hanson (2). As an impact could have different consequences if a new trauma had occurred, a detailed analysis was performed for teeth exhibiting fracture healing with formation of hard tissue. Thus, to group H were assigned teeth showing formation of hard tissue in fracture, fragments close together and no visible fracture line, i.e. fusion of fragments had occurred. To group Ha were assigned teeth showing formation of hard tissue between the fragments, but in which a faint and indistinctly outlined fracture line was visible in radiographs at the last control. The reason for this subdivision of teeth with fractures healed with formation of hard tissue was the assumption that the Ha type of healing may represent a weaker resistance to a new impact than teeth showing fusion of fragments in group H. Such information could then be related to the likelihood of a new luxation of the coronal fragment. To group HS were assigned teeth showing interposition of a bony bridge, separated from fragments by a line of soft tissue. Group S consisted of teeth showing interposition of only soft tissue between the separated fragments, with or without smoothed sharp edges of fracture. Finally, to group NH were assigned teeth showing no healing i.e. occurrence of radiolucency in the alveolar bone, adjacent to fracture, usually with widening of the diastase between the fragments.

Obliteration of the pulpal lumen

Obliteration of the pulpal lumen was recorded when progressive apposition of hard tissue on the dentinal walls was observed, often leaving only a tiny pulpal lumen in one or both of the fragments.

Time of treatment

The material was divided into two groups: teeth treated between 1959 and 1976 and those treated between 1979 and 1995. This was done in an attempt to assess eventual differences in frequencies of survival due to the changes in treatment procedures, e.g. a shift from 3 months of rigid splinting of all root fractured teeth to a non-flexible or slightly flexible immobilization adapted to the severity of injury or use of calcium hydroxide in endodontic therapy in root-fractured teeth (13, 19–21).

Statistical evaluation

Statistical evaluations were made using chi-squared and Fisher's exact tests, and the limit of statistical significance was set at $P = 0.05$.

Results

In the material as a whole, 42 teeth (8%) were extracted at first examination for various reasons (Fig. 1). These teeth were excluded from evaluations of controlled teeth but included in the final survival assessment of root-fractured teeth. Of the remaining 492 teeth, 383 (78%) showed fracture healing (groups H, Ha, HS and S) while 109 (22%) exhibited no healing after an observation time (group NH).

Healing of fracture

For practical reasons, 383 teeth that showed fracture healing were divided into two groups, one consisting of 325 teeth showing *no posthealing complication* during follow up, and the other consisting of 58 teeth in which a *posthealing complication* had taken place during the observation period.

Teeth with no posthealing complication

The 325 teeth in which no complication occurred after healing were followed up for 12–124 months (mean = 56.7 months) after the injury. In more than half of these teeth, the fracture was located in the middle part of the root (group M) and healed with interposition of soft tissue between the fragments (group S). The length of control time was similar across all groups, either measured according to the position of fracture or the type of fracture healing. These teeth with their mean control time in months are presented in Table 2.

Table 2. Mean follow-up time in months (mean m) for the 325 teeth showing healing of fracture and *no posthealing complication*, distributed according to the position of fracture in one-third of the root: C (cervical), CM (cervical and middle), M (middle) and A (apical part of the root), and the type of fracture healing: H (healing with hard tissue, fusion), Ha with hard tissue, fracture line discernible, HS (with interposition of hard and soft tissue) and S (with interposition of only soft tissue)

	Position in the root					
Healing type	C	C/M	M	A	Total	Follow up
H	9	6	41	32	86	67.7
Ha			18	9	27	53.1
HS		2	13	8	23	53.7
S	13	23	112	40	188	42.7
	22	31	183	89	325	
Follow up	51.8	57.7	54.2	55.9	56.7	

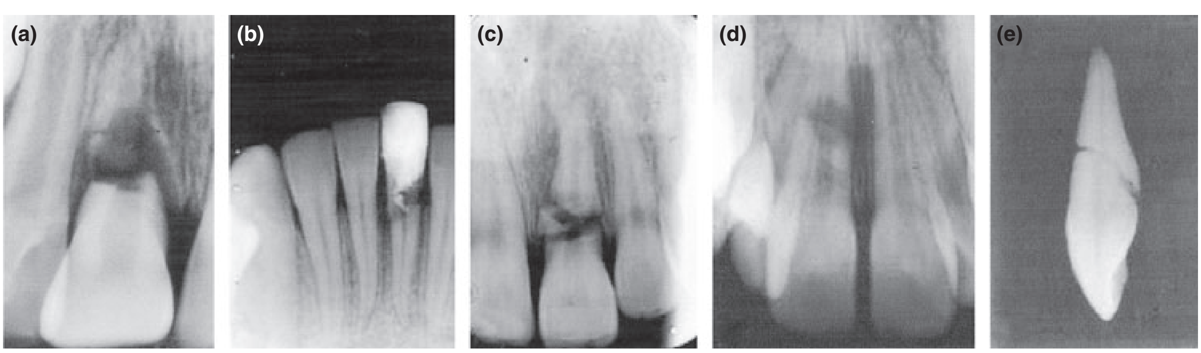

Fig. 1. Immediate or delayed extraction of root fractured teeth. (a–c) Two upper and a lower incisor showing complicated cervical fractures 1–3 days after injury, extracted at the first examination. (d) Right central incisor 8 days after injury, with, as it appears, a fracture in middle part of the root. Clinically, there were crowding of teeth, loosening of the coronal fragment and a buccal fistula. (e) Radiograph of the extracted tooth (in d) shows an oblique root fracture.

Teeth with complications after fracture healing
During the observation time, a posthealing complication occurred in 58 teeth. In 47 of the teeth it was a new luxation of the coronal fragment. In the other 11 teeth, the mobility of coronal fragment increased after fracture healing to such an extent that the tooth had to be extracted.

In total, posthealing complications occurred most frequently in teeth with a fracture that healed with interposition of soft tissue between the fragments (group S) and in teeth with fracture in the cervical area of the root (group C). When these groups were separately compared with other healing or position groups, the higher frequency of new fractures was significant at $P = 0.012$ and 0.001 respectively (Table 3).

New luxation injuries
New injuries causing subluxation or luxation with dislocation of the coronal fragment occurred in 47 teeth, 7–78 months (mean = 37 months) after the initial injury. Upon new injury, all teeth exhibited a completed root development. No statistically significant correlation was found between frequency of new luxation and time of occurrence after initial injury. The highest frequency of a new injury was found in teeth with fracture in the cervical area of the root (28%) ($P = 0.001$). Regarding healing type of fracture, new injury was significantly more frequent in group S when compared with other healing groups ($P = 0.012$) (Table 3). A new luxation occurred in six teeth in which the fracture healed with fusion of fragments. In four of these, the new separation of fragments occurred along the previous fracture line, while in two teeth the fracture showed a line that differed from the previous one, possibly indicating the occurrence of a new root fracture (Table 3, Figs 4 and 5). There was no difference in the frequency of new injuries between groups H and Ha.

In 21 of 47 new luxated teeth, the new fracture injury healed spontaneously, with or without splinting. The other 26 teeth showed the appearance of radiolucency in the periradicular bone, related to root fracture. Of these, 19 were extracted and seven treated endodontically. After this treatment, four teeth showed healing while three teeth that exhibited no healing were extracted. Clinical status, treatment and its outcome are presented in Table 4.

Teeth with increased mobility of the coronal fragment
Increased mobility of the coronal fragment after healing of fracture was recorded for 32 teeth. In 21 of these, the mobility of the coronal fragment declined

Table 4. Status and outcome in 47 teeth with new luxation of the coronal fragment, distributed with respect to the degree of luxation, fixation or no fixation at new injury and subsequent healing or no healing, i.e. extraction or endodontic treatment with following result and the position of fracture in the one-third part of the root at the time of initial injury: C (cervical), CM (cervical and middle), M (middle) and A (apical part of the root)

Fracture position	*n*	Fixation		Healing		Direct extraction	Endodontics: healing	
		+	−	+	−		+	−
C (12)								
Subluxation	4	1	3	2	2	2		
Luxation	8	5	3		8	8		
CM (4)								
Subluxation	2	2		2				
Luxation	2	1	1		2	1		1
M (25)								
Subluxation	10	5	5	8	2	1	1	
Luxation	15	8	7	5	10	6	2	2
A (6)								
Subluxation	1		1	1				
Luxation	5	5		3	2	1	1	
Total	47	27	20	21	26	19	4	3

Within parentheses are numbers of teeth in a group.

Table 3. Occurrence of 58 posthealing complications, such as new luxation or looseness of the coronal fragment, leading to extraction, in 383 teeth, distributed according to the type fracture healing: H (healing with hard tissue, fusion), Ha (with hard tissue, discernible fracture line), HS (with interposition of hard and soft tissue), S (with interposition of only soft tissue), and the position of the fracture in one-third of the root: C (cervical), CM (cervical and middle), M (middle) and A (apical)

	Type of healing				
	H	Ha	HS	S	Total
Number of teeth	96	29	25	233	383
New luxation	6 (6)	1 (3)	3 (12)	37 (16)	47 (12)
Loosening of the coronal fragment	0	0	0	11 (5)	11 (3)
	Position of fracture				
	C	CM	M	A	Total
Number of teeth	43	36	209	95	383
New luxation	12 (28)	4 (11)	25 (12)	6 (6)	47
Loosening of the coronal fragment	10 (23)	1 (3)			11

Values within parentheses are expressed in percentage.
Healing S vs healing H-HS: $P = 0.012$.
Position C vs positions CM-A: $P = 0.001$.

during observation time, to none in 18 and only slightly increased in three teeth. Showing no other clinical or radiographic symptoms these teeth were allotted to the group of teeth with no posthealing complication (Table 2). In the remaining 11 teeth, the looseness of the fragment increased to such an extent that the tooth had to be extracted, during the observation time. The fractures were positioned in the cervical part of the root (groups C and CM) and had healed with interposition of soft tissue between fragments (group S) (Table 3).

Formation of hard tissue in the pulp

Two types of hard tissue formation were observed in the pulp. In the first type, present in 171 (45%) of the 383 teeth, progressive apposition of hard tissue on the dentinal walls slowly obliterated the pulpal lumen. The pulpal lumen was diminished to some degree in only the coronal fragment of 15 teeth, in only the apical fragment of 57 teeth and in both fragments in 119 teeth. Obliteration of the pulpal lumen had no adverse effect on the survival of these teeth.

The other type of hard tissue formation was localized and clearly related to the fracture site, while the rest of the pulpal lumen remained of normal size and appearance. It was only seen in teeth showing fusion of fragments (group H) in 37 of 53 immature and 9 of 36 mature teeth. In immature teeth, it was seen 6–8 months (mean = 7 months) and in mature teeth 49–99 months (mean = 72 months) after the injury. The formation of localized hard tissue was significantly more frequent in immature teeth compared with mature teeth ($P = 0.001$, Figs 2 and 3, Table 5).

No fracture healing

No healing, i.e. pulp necrosis and appearance of radiolucency in the periradicular bone, next to the root fracture, with or without widening of the space between fragments, (group NH) occurred in 109 (20%) of the 534 root fractured teeth. Fourteen teeth (13%) were extracted after an observation time of 15–89 days (mean = 49 days) after the injury, and the remaining 95 teeth were endodontically treated (Table 6).

Healing or non-healing after endodontic treatment

Healing after endodontic treatment, i.e. resolved periradicular radiolucency and re-established periodontal space bordered by lamina dura, occurred in 75 of 95 treated teeth (79%), followed for an average of 66 months after injury (Fig. 6). Healing had not occurred in 20 teeth (21%). One of these teeth had a fracture in the cervical part of the root (group C), four had a fracture in the cervical and middle part of the root (group CM), 10 had a fracture in the middle part of the root (group M) and five had a fracture in the apical part of the root (group A) (Table 6). Teeth in which endodontic treatment had failed, i.e. the radiolucency related to fracture was persistent or increased, were extracted 14–95 months (mean = 41 months) after the injury. The observation times for all endodontically treated teeth are included in the survival summary of root-fractured teeth (Table 7).

Summary of survival rate within the observation time

Frequencies of survival or loss of the teeth and length of observation time in the material as a whole are summarized in Table 7. Survival or healing of fracture was observed in 425 teeth (80%). In 348 teeth the fracture healed spontaneously and in 78 teeth it healed after endodontic therapy, subsequent to initial or new injury. These teeth were followed up for 12–153 months (mean = 63 months) after the initial injury. No healing occurred in 109 teeth (20%). Forty-two teeth were extracted at the first appointment, 30 after an observation period of 15–119 days (mean = 30 days), subsequent to initial or new injury, 25 after unsuccessful endodontic therapy and 11 due to pronounced looseness of the coronal fragment. These teeth were followed for 29–126 months (mean = 58.5 months) from the initial injury to the extraction.

Comparisons of teeth treated between 1959–1976 (318 teeth during 17 years) and 1977–1995 (216 teeth during 19 years) revealed no statistically significant difference in the frequency of teeth survival, length of follow up or occurrence of posthealing complication.

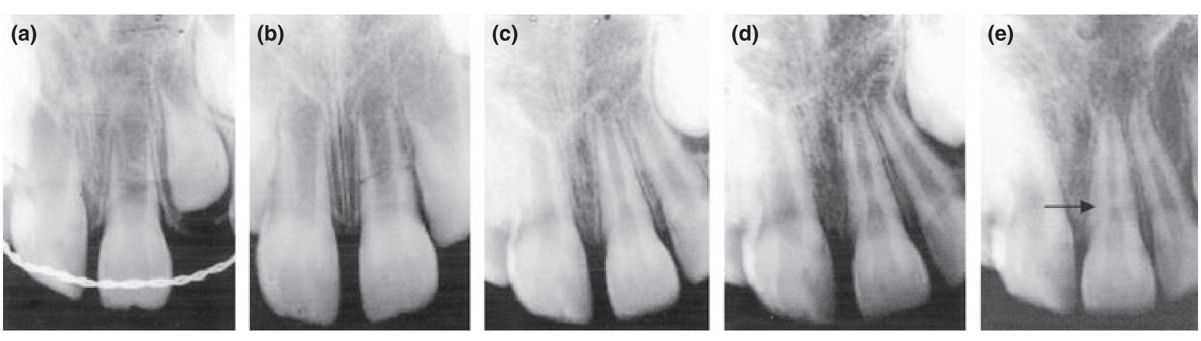

Fig. 2. Limited hard tissue formation in the pulp, adjacent to fracture. (a, b) On the day of injury and 4 months later; fracture in the middle part of the root with no hard tissue formation in the pulp. No hard tissue formation in the pulp. (c–e) Controls obtained after 1, 3 and 6 years show fusion of fragments and localized hard tissue formation in the pulp, adjacent to the fracture (arrow).

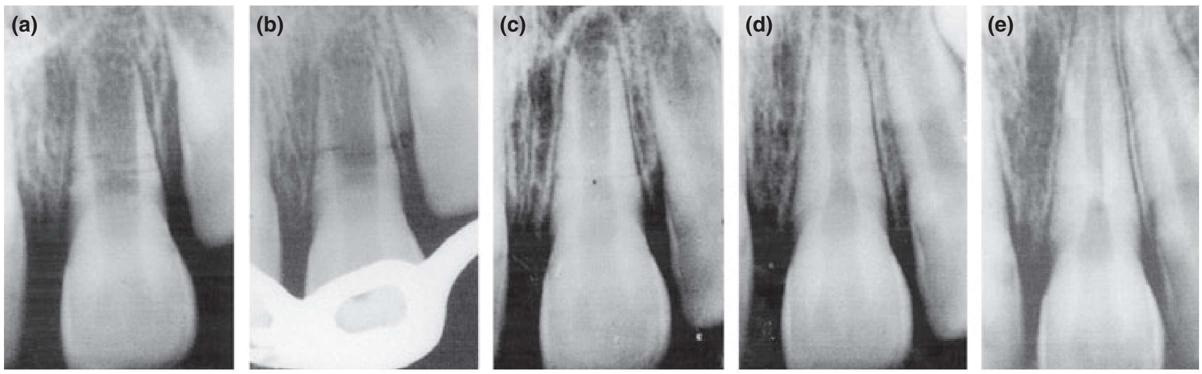

Fig. 3. Localized and more extensive hard tissue formation in the pulp. (a–c) On the day of injury and 3 and 6 months thereafter; fracture in the cervical part of the root. (d, e) Controls after 19 months and 6 years show fusion of fragments and a more extensive hard tissue formation, adjacent to the previously seen root fracture; the remaining pulp is of normal size [from *Cvek* et al. (10)].

Table 5. Root fractured teeth showing healing type H (healing with hard tissue, fusion or Ha (healing with hard tissue, discernible fracture line) and formation of hard tissue in the pulp, adjacent to root fracture, HP, distributed according to the stage of root development: stage 1, 2 and 3 (less than one-third, one-half and two-thirds of the root length, 4 (almost completed root length, open apical foramen) and 5 (completed root development, narrow apical foramen)

	Stage of root development						
	1	2	3	4	5	NK	Total
Healing H	3	17	12	22	35	7	96
HP	2	12	10	13	9	2	48
		70%			25%		
Healing Ha			1	2	23	3	29
HP							0

NK, root development was not known. Chi-squared test: immature vs mature teeth ($P = 0.001$).

Table 6. Frequency of extraction and healing or no healing after endodontic treatment in 109 teeth showing no healing after the initial injury, distributed according to the position of fracture in one-third of the root: C (cervical), CM (cervical and middle), M (middle) and A (apical part of the root), and per cent and mean value of follow-up duration for the extractions in days and for endodontic treatments in months

	Position in the root					Follow-up time (mean)
	C	CM	M	A	Total	
Number of teeth	7	9	63	30	109	
Extraction	6	4	4		14 (13)	49 days
Endodontics	1	5	59	30	95 (87)	
Healing		1	49	25	75 (79)	66 months
No healing	1	4	10	5	20 (21)	41 months
Total survival	0	1 (11)	49 (78)	25 (83)	75 (69)	
Total tooth loos	7 (100)	8 (89)	14 (22)	5 (17)	34 (31)	

Values within parentheses are expressed in percentage.

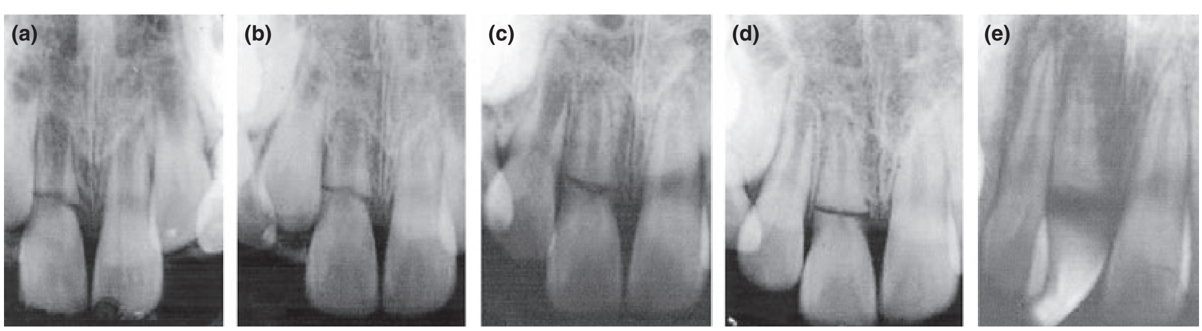

Fig. 4. Second luxation of the coronal fragment. (a) An immature incisor with horizontal, cervical root fracture. (b–d) Radiographs taken after 2, 9 and 17 months show healing with interposition of soft tissue between fragments. (e) After 49 months the tooth suffered a new luxation injury of the coronal fragment and the tooth had to be extracted [from *Cvek* et al. (11)].

Discussion

It is important to note that all treatments and controls in the present study were solely carried out at the Department of Pediatric Dentistry, Eastman Institute, Stockholm and cannot be looked upon as an epidemiologic survey. Regarding the frequency of new injuries, for example, patients could seek help at the other dental clinics or hospitals within Stockholm County. The long control periods were possible due to free dental care given to all Swedish children and adolescents up to 19 years of age. The follow up was also prolonged by the endodontic treatments and because many patients received additional treatment at the Eastman Institute's

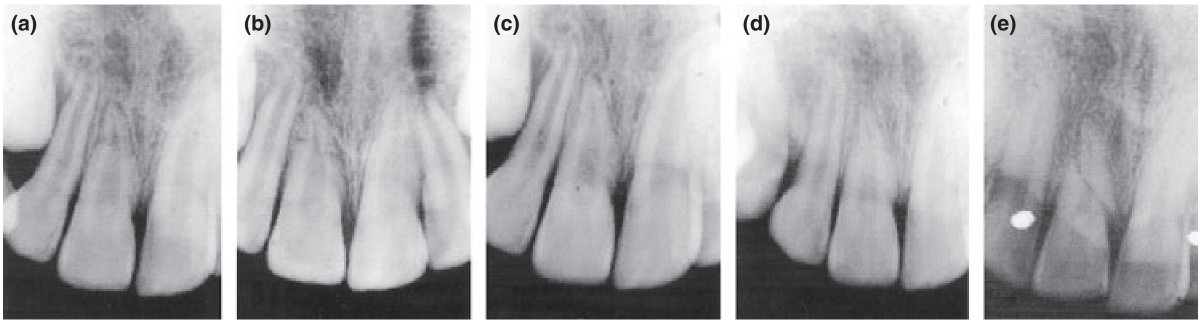

Fig. 5. New luxation of the coronal fragment. (a) A mature incisor showing a fracture in the apical area of the root. (b–d) Radiographs taken 3, 16 and 42 months after injury show healing with fusion of the fragments. Three months after the last control a new luxation of the coronal fragment occurred and radiographs taken 7.5 years after initial injury show healing fracture with interposition of soft tissue and the line of new fracture which apparently differs from the previous one.

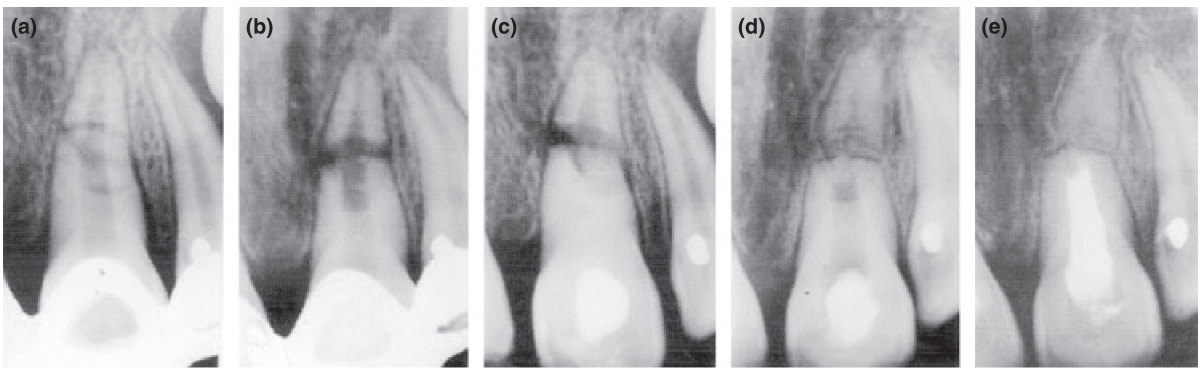

Fig. 6. Successful endodontic therapy of a non-vital root-fractured incisor. (a) Oblique fracture in the middle part of the root. (b, c) Five weeks after injury, appearance of periradicular radiolucency and filling of coronal fragment with calcium hydroxide. (d) Periradicular healing and formation of a hard tissue barrier in the coronal fragment 18 months thereafter. (e) Status 6 years after filling of the coronal root fragment with gutta–percha.

Table 7. Healing or survival or extraction in 534 teeth with intra-alveolar root fracture, distributed according to the position of fracture in one-third of the root: C (cervical), CM (cervical and middle), M (middle) and A (apical part of the root), healing or no healing of fracture and mean observation time in days for early extracted teeth and in months for teeth showing healing, after an injury or endodontics and late extractions, after first and/or new injury or unsuccessful endodontic treatment

	Fracture position					Observation time (mean)
	C	C/M	M	A	Total	
Number of teeth	77	47	285	125	534	
Healing/survival						
After first and second luxation	23	31	197	94	345	82 months
After endodontic therapy, after first or second luxation		3	52	25	80	65 months
Total tooth survival	23 (30)	34 (72)	24 (86)	119 (96)	425 (80)	63 months
Extraction/no healing						
At first examination	27	2	13		42	2 days
After a short observation	16	5	10	1	32	49 days
After endodontic failure	1	5	13	5	24	46 months
For the loosening of coronal fragment coronal fragment	10	1			11	41 months
Total tooth loss	54 (70)	13 (28)	36 (13)	6 (5)	109 (20)	30 months

Values within parentheses are expressed in percentage.

other departments, from which the patient records were made available for the present study. An attempt to keep the loose coronal fragments as a space maintainer also contributed to the prolonged survival time of these teeth. Unfortunately, the records of patients treated between 1959 and 1986, kept in Stockholm County's Central Achieves, were not available for the additional screening regarding time and number of repeated fixation of mobile coronal fragments or the reasons for immediate extractions. Data available for patients treated after this time were considered not representative for the whole material and therefore were not considered in the study.

The poorest prognosis was found in teeth showing horizontal fracture in the cervical part of the root (group C) and about 70% of these teeth required extraction. The reason for the low frequency of survival was thought to be the position of the fracture in combination with healing by interposition of soft tissue in between the fragments, which seemed to decrease the resistance of the coronal fragment to new impacts or even normal mouth activities (11, 14). However, healing of the cervical fracture did occur in about 30% of teeth, making it worthwhile and advisable to adopt a conservative treatment approach before other more arduous alternatives are applied.

For teeth with fractures in the other places in the root (groups CM, M and A), the prognosis was found to be very good, despite the inclusion of immediately extracted teeth, endodontic interventions and occurrence of posthealing complications. The frequency of survival in these teeth was 88%, over an average observation time of more than 5 years. No significant difference in frequency and type of healing or location in the root was found when groups CM, M and A were compared. This may indicate that, in these teeth, the position or type of fracture healing are of more academic than of clinical interest.

Obliteration, i.e. progressive hard tissue apposition on the dentinal walls, had no adverse effect on the survival of root-fractured teeth, and this is in accordance with previous reports (22–26). The formation of localized hard tissue in the pulp, adjacent to the fracture site, has been seen in earlier cases (11). However, in the present material it was observed frequently, mostly in radiographs of immature teeth. Involvement of the pulp in fracture repair has been discussed in a number of studies (22–25, 27) but the conclusions are poorly supported by the experimental series. However, the present finding of frequent formation of hard tissue localized to the fracture area may support the view that signal substances, released by fracture of hard or lacerated tissues, may irritate the pulpal cells to differentiate and form reparative hard tissue, closing the fracture gap and fusing the root fragments. It may also demonstrate a high healing capacity of the young dental pulp.

The frequency of healing after endodontic treatment was high – 79% of 95 treated teeth – which seems to have contributed considerably to the high survival rate of root-fractured teeth (Tables 6 and 7). The healing frequency was also comparable with those reported in previous endodontic studies (19–21).

In an attempt to clarify whether the frequency of tooth survival and occurrence of posthealing complications had changed over time, the material was divided into two groups consisting of teeth treated between 1959–1976 and 1977–1995. However, no significant differences in survival rates or frequencies of posthealing complication were found. This may be because changes in attitudes towards new or improved treatments take time to become accepted in teaching and clinical practice. In a clinical material, changes in treatment procedures could therefore be found on both sides of an arbitrarily chosen time limit.

The significance of various clinical and treatment factors for healing of root-fractured teeth has previously been presented and discussed in detail (10–13). The primary aim of the present study was therefore to assess the survival rate of young fractured teeth including parameters not previously studied, such as the frequency of teeth extraction at first examination or shortly after, the frequency and outcome of posthealing complications and healing frequency in endodontic treatments. The teeth were followed up for more than 5 years (mean = 65 months) after the initial injury, which is considered sufficient for a long-term study. Furthermore, the inclusion of new parameters in the evaluation of survival rate makes any comparison of the final results with the results in the previously reported long-term studies difficult.

Most injuries to the teeth occur between 8 and16 years (17), a period well covered by the present material. Thus, it is unlikely that a longer observation time, including higher ages, would reveal more new injuries or treatment failures. However, when these do occur, it may be convenient to consider the survival frequency in conservatively treated teeth before a decision on more arduous treatment is taken. The use of implants, for example, in the anterior region is sometimes very difficult and may lead to aesthetic or integration failure (28).

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