

Healing of 400 intra-alveolar root fractures.

2. Effect of treatment factors such as treatment delay, repositioning, splinting type and period and antibiotics

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Abstract – This is the second part of a retrospective study of 400 root-fractured permanent incisors. In this article, the effect of various treatment procedures is analyzed. Treatment delay, i.e. treatment later than 24 h after injury, did not change the root fracture healing pattern, healing with hard tissue between fragments (HH₁), interposition of bone and/or periodontal ligament (PDL) or pulp necrosis (NEC). When initial displacement did not exceed 1 mm, optimal repositioning appeared to significantly enhance both the likelihood of pulpal healing and hard tissue repair (HH₁). Significant differences in healing were found among the different splinting techniques. The lowest frequency of healing was found with cap splints and the highest with fiberglass or Kevlar[®] splints. The latter splinting procedure showed almost the same healing result as non-splinting. Comparison between non-splinting and splinting for non-displaced teeth was found to reveal no benefit from splinting. With respect to root fractures with displacement, too few cases were available for analysis. No beneficial effect of splinting periods greater than 4 weeks could be demonstrated. The administration of antibiotics had the paradoxical effect of promoting both HH₁ and NEC. No explanation could be found. It was concluded that, optimal repositioning seems to favor healing. Furthermore, the chosen splinting method appears to be related to healing of root fractures, with a preference to pulp healing and healing fusion of fragments to a certain flexibility of the splint and possibly also non-traumatogenic splint application. Splinting for more than 4 weeks was not found to influence the healing pattern. A certain treatment delay (a few days) appears not to result in inferior healing. The role of antibiotics upon fracture healing is questionable.

In a previous study of intra-alveolar root fractures of 400 permanent incisors, the effect of pre-injury and injury factors was analyzed with respect to their influence upon healing outcome (1).

In a previous study of 208 root-fractured incisors, serious doubt was raised concerning the effect of splinting and its duration on the frequency and type of fracture healing (2). In that

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Key words: root fractures; pulp healing; periodontal healing; repositioning; splinting methods; splinting period; treatment delay; antibiotics

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study, the teeth had been treated in the period 1959–1973, i.e. before the era of adhesive dentistry; and most of these root fractures were rigidly splinted with either gold or acrylic cap splints or arch bars (3). Since then, immobilization with cap splints or orthodontic appliances (with cemented bands) have generally been abandoned; and replaced by various modifications of adhesive techniques, where interdental stabilization is achieved by Kevlar® (Du Pont, Wilmington, DE, USA), fiberglass or metal bars bonded to the coronal fragment of the root-fractured incisor. Such splinting techniques are considered to be less traumatogenic and less time consuming in their application. However, the results with respect to frequency and type of fracture healing have only been studied in one clinical investigation, where a significant relationship was found between the cementation of orthodontic bands united with acrylic and the use of an adhesive technique (Protemp® [3m ESPE AG, Seefeld, Germany] bonded to the labial surfaces) and later development of pulp necrosis in the coronal fragment with the former procedure having a larger frequency of pulp necrosis (4).

The aim of the present investigation was to study the effect of treatment factors upon healing with special reference to the effect of treatment delay, effect of optimal repositioning, type and duration of splinting and antibiotics on the occurrence and type of root fracture healing.

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 statistical analysis of the additional material were identical to the previous study (2). However, a few extraclinical parameters were included, such as sex, mobility of the coronal fragment at the time of injury, and three new splinting procedures with varying rigidity (see later). The new splinting techniques were introduced to simplify the fixation procedure and were generally based on adhesive bonding (3). This topic will be further addressed in a following study.

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 (2). In the present study, the types of splints used will be described in more detail.

Types of splints

Orthodontic band-arch wire splint

Twenty-six teeth were splinted with adapted and cemented orthodontic bands connected with an arch wire (Fig. 1).

Cap splint

After an initial impression was taken with alginate, a temporary fixation was applied and then a cap splint was fabricated in either gold or acrylic; and usually inserted after 6–8 h, maximum 24 h, after impression taking (Fig. 2).

Proximal bonding with composite

The proximal surfaces of the injured and adjacent teeth were etched and united by placing composite on the etched surfaces (Fig. 3).

Bonded orthodontic wire

The labial surfaces were spot etched and composite resin or brackets was used to secure the wire to the etched enamel surface (Fig. 4). An orthodontic wire of varying diameter (0.5–0.75) was adapted and applied to fit the labial surfaces of the injured and adjacent teeth.

Bonding with a Kevlar® or fiberglass splint

The labial surfaces of the injured and adjacent teeth were etched. Light-cured fine-particle flowable hybrid composite (Tetric flow®, Vivadent, Schaan, Liechtenstein) was applied to the etched surfaces. Two or three fiberglass (obtained from fiberglass rowing) or twined Kevlar® fibers were cut to size, soaked in the unfilled resin (Concise® enamel bond; 3m ESPE AG) and placed on the teeth with a forceps (Fig. 5). During light curing, the position of the injured tooth was ensured by digital pressure. This technique has been described in detail by Anderson et al. (4).

No splinting

In 56 teeth, no splinting was carried out for the following reasons. In 26 cases, a fracture was not seen in radiographs at the first examination; the tooth was only subluxated and registered as subluxation. 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; treatment was, therefore, not found as indicated.

Follow-up

The follow-up period for healed fractures ranged from 1 to 13 years ($x = 3.6$ years ± 3.0). During the observation period, 30 teeth suffered a new injury; and in these patients, registration was

Fig. 1. Orthodontic bands + arch bar splint.

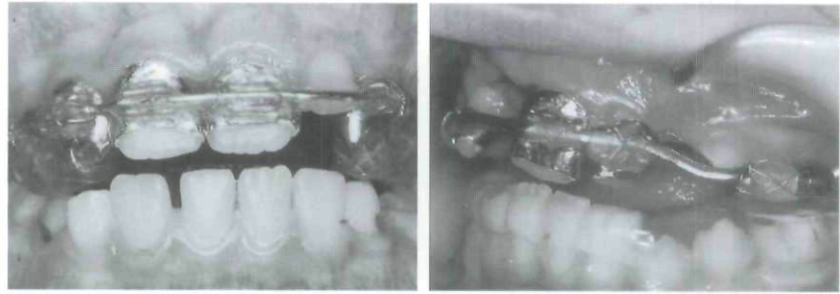


Fig. 2. Acrylic or gold cap splints.

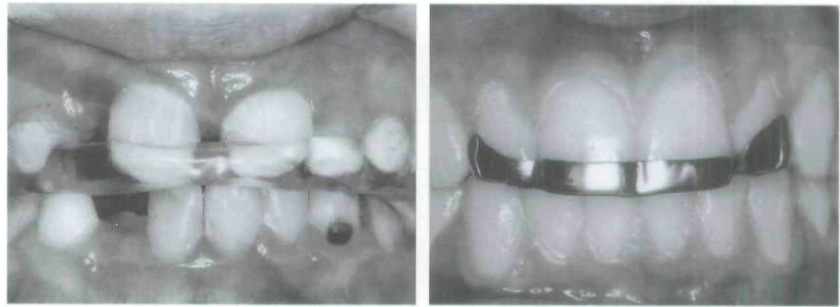


Fig. 3. Acid etch and composite splint.

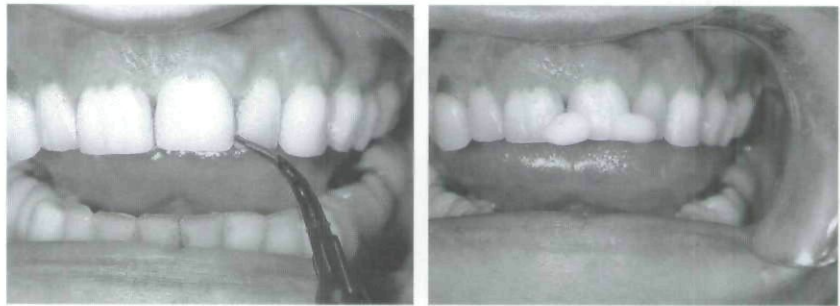
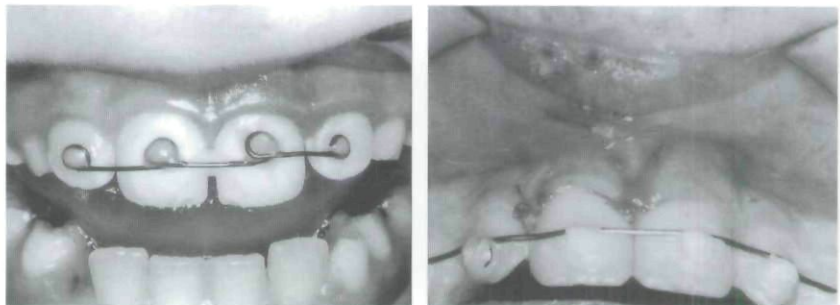


Fig. 4. Bonded metal wire splint.



terminated with the last radiographics obtained before the second injury.

Healing classification

At the final radiographic control, fracture healing was classified into four groups according to Andreasen and Hjørtting-Hansen (7): 1) Healing with hard tissue (fragments are in close contact and the fracture line is not or only slightly visible) (HH₁); 2) Healing with interposition of hard and soft tissue between the fragments (fragments are separated by ingrowth of hard tissue, surrounded by a peridental-

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).

Groups 2 and 3 were considered to be variations of the same healing pattern and therefore pooled in the statistical analyses and designated periodontal ligament (PDL).



Fig. 5. Splinting with Kevlar® or fiberglass.

The results were statistically analyzed using Fisher's exact test, chi-square test and Mantel-Haenszel analysis. 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 (1).

Results

Treatment delay

It appears from Fig. 6 that there was no significant relation between the time of treatment after injury and type of healing. In order to avoid bias, the treatment effect was analyzed only for teeth, which actually were repositioned and splinted (not for untreated cases). When the material was stratified for factors such as root development and type and extent of displacement of the coronal fragment, no significant relationship with treatment delay could be established.

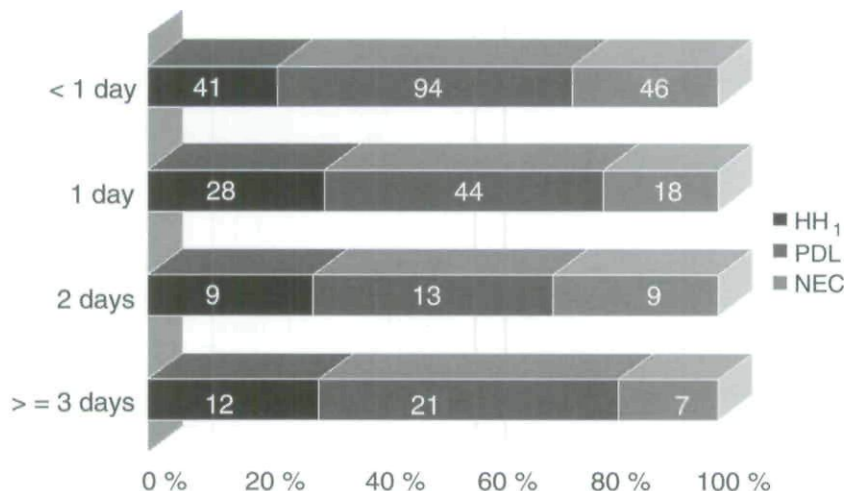
Repositioning

It appears from Table 1, that repositioning was significantly related to type of healing, when

diastasis before repositioning was quantified into four groups. It appears that this relationship was mainly related to a dislocation up to 1 mm. As this might suggest that stretching of the pulp could take place, a further analysis was made where sensibility of the pulp at the time of the injury was tested against dislocation. It was shown that pulp sensibility was very frequent with a dislocation of up to 0.5 mm and still occurred in about one-fourth of the cases with displacement from 0.5 to 1 mm.

Type of splinting

The various splinting types used represented a variety of new traumas to the injured teeth during application, varying possibility of optimal oral hygiene in the trauma region, as well as varying stability during fracture healing. As it appears in Table 2, there was a significant difference between splinting types and later healing events. To further characterize these differences, a stratified analysis was made, where each splinting type was compared with others with respect to NEC and HH₁. It appears from Tables 3–5 that there were significant variations in the healing outcome following the use of the various splints. Thus, orthodontic bands



P = 0.50

Fig. 6. Treatment delay related to healing. HH₁, healing with hard tissue between fragments; PDL, periodontal ligament; NEC, pulp necrosis.

Table 1. Relationship between fracture healing and initial diastasis between fragments and subsequent repositioning (optimal ~ incomplete)

	Healing type				Significance			
	1 (%)	2	3	4 (%)	HH ₁	PDL	NEC	HEAL
Diastasis (0.1–0.5 mm)								
Optimal	9 (41)	11	0	2 (9)	0.001	0.88	0.03	0.001
Incomplete	2 (6)	14	6	14 (38)				
Diastasis (0.6–1.0 mm)								
Optimal	4 (29)	8	2	0 (0)	0.13	0.72	0.02	0.02
Incomplete	1 (5)	10	3	7 (33)				
Diastasis (1.1–2.0 mm)								
Optimal	1 (8)	6	0	5 (41)	0.34	0.81	0.81	0.34
Incomplete	0 (0)	9	2	12 (52)				
Diastasis (2.1 mm)								
Optimal	1 (8)	8	0	3 (25)	1.0	0.42	0.25	0.39
Incomplete	1 (5)	6	2	9 (50)				

HH₁, healing with hard tissue between fragments; PDL, periodontal ligament; NEC, pulp necrosis; HEAL, healing.

+ arch bar and Kevlar[®]/fiberglass splints resulted in the greatest number of HH₁.

With respect to PDL healing, no significant difference could be detected (Tables 3–5). Concerning NEC, a significant reduction was found when Kevlar[®]/fiberglass splints were compared with almost all other splints (Tables 3–5).

Length of splinting

Neither the univariate nor stratified analyses showed significant relation to the length of splinting period. No difference was found for healing of teeth splinted for 2 months or less and for longer splinting periods (Fig. 7). A special analysis was made for cervical fractures. These fractures appeared to have the same average splinting period as fractures located in the mid- or apical root thirds.

Non-splinting

Altogether 56 teeth were not splinted. As it appeared from the records, these teeth suffered a moderate injury. In Table 6 the healing results are given for non-splinted teeth compared with splinted teeth without dislocation. There was no difference in fracture healing ($P = 0.46$).

When the same analysis was performed on teeth with no radiographic diastasis, the results were on the line of significance (i.e. with splinted teeth),

Table 2. Relationship between splinting type and healing

Splinting type	HH ₁ (%)	PDL (%)	NEC (%)	n
Arch bar + orthodontic bands	11 (42)	9 (35)	6 (23)	26
Cap splint	58 (25)	124 (52)	54 (23)	54
Composite	1 (10)	5 (50)	4 (40)	10
Composite + arch bar	3 (11)	13 (46)	12 (43)	28
Kevlar [®] /fiberglass	17 (39)	23 (52)	4 (9)	44

HH₁, healing with hard tissue between fragments; PDL, periodontal ligament; NEC, pulp necrosis.

having more prominent PDL healing, but no significant difference in HH₁ or NEC.

Antibiotics

A slightly negative effect was found on the frequency of NEC and positive effect on HH₁ from antibiotic treatment; both effects, however, were not significant. It was tested whether the use of antibiotics was influenced by the severity of the trauma (i.e. $\pm$ dislocation, $\pm$ mobility of fragment); but no such relationship could be established. However, in this analysis, it should be considered that only 13 cases received antibiotic treatment, which makes a detailed stratified statistical analysis impossible.

Discussion

This study concerns the fate of 400 root-fractured incisors and should be seen as an extension of the previous study of 208 teeth, where only non-adhesive and usually rigid splinting methods were used (2). As direct bonding to enamel became a reality in the late 1960s, it was obvious that such a procedure should be introduced in the splinting armamentarium. Thus, new splinting procedures were used in the second part of the study, allowing four new splinting procedures to be compared (see later).

As expected, the stratified analysis of the 400 root-fractured incisors showed generally the same significant relationship to the clinical variables as the earlier study comprising 208 root fractures (2) and a second clinical study of 95 root fractures (5). In essence, the healing outcome of a root fracture appears to be primarily related to the stage of root formation and extent of injury (i.e. dislocation of the coronal fragment). This relationship makes the healing scenario very similar to that of tooth luxation, where a wide-open pulp canal apparently facilitates healing (6). In previous clinical investiga-

Table 3. Significance levels of an intergroup analysis of various splinting types in relation to a frequency of healing with hard tissue between fragments (HH₁) based on a Fisher's test

HH ₁	Orthodontic bands + arch bar	Cap splint	Composite	Composite + arch bar
Cap splint	0.08			
Composite	0.14	0.49		
Composite + arch bar	0.01	0.15	0.59	
Kevlar®/fiberglass	0.95	0.08	0.13	0.02

Table 4. Significance levels of an intergroup analysis of various splinting types in relation to the frequency of periodontal ligament (PDL) healing based on a Fisher's test

PDL	Orthodontic bands + arch bar	Cap splint	Composite	Composite + arch bar
Cap splint	0.12			
Composite	0.46	0.99		
Composite + arch bar	0.54	0.68	0.99	
Kevlar®/fiberglass	0.23	0.89	0.99	0.80

Table 5. Significance levels of an intergroup analysis of various splinting types in relation to frequency of pulp necrosis (NEC) healing based on a Fisher's test

NEC	Orthodontic bands + arch bar	Cap splint	Composite	Composite + arch bar
Cap splint	0.82			
Composite	0.41	0.25		
Composite + arch bar	0.21	0.03	1.0	
Kevlar®/fiberglass	0.15	0.06	0.03	0.002

tions by one of the authors (5), root fractures were likened to luxation injuries, but only of the coronal fragment – and with the same parameters that determined long-term prognosis.

Root fracture healing is by its nature a complicated event, being very dependent upon pulpal and periodontal healing processes and bacteria entering the coronal part of the pulp, which subsequently will arrest healing processes in the fracture area. Under optimal conditions (no displacement of the coronal fragment), healing processes will take place by differentiated odontoblasts and cementoblasts whereby hard tissue union between the fragments (7). With limited dislocation between fragments, competition between pulpal and PDL healing takes place; and preference will be given to PDL healing, whereby cementum will be formed on each fragment and an extension of the lateral PDL will enter the fracture line. Under optimal conditions, however, when the entire pulp is intact after the injury, almost ideal healing conditions exist, where the root fracture is healed by the pulp site by formation of a new dentin callus, while limited invasion of PDL tissue between the fragments from the periphery ensures cementum formation between the fragments (5, 7).

Repositioning

It appears that optimal repositioning optimized HH₁ and lowered NEC. The HH₁ effect could be explained by the shorter healing distance between fragments, possibly favoring pulp healing instead of healing processes from the PDL. This effect was also found in a previous long-term investigation of root fractures (4), where fracture location had no effect on pulp survival. The effect of repositioning upon NEC could be reduction of the risk of invasion of bacteria through a minimal coagulum in well-repositioned cases, as a coagulum is a good substrate for bacterial growth.

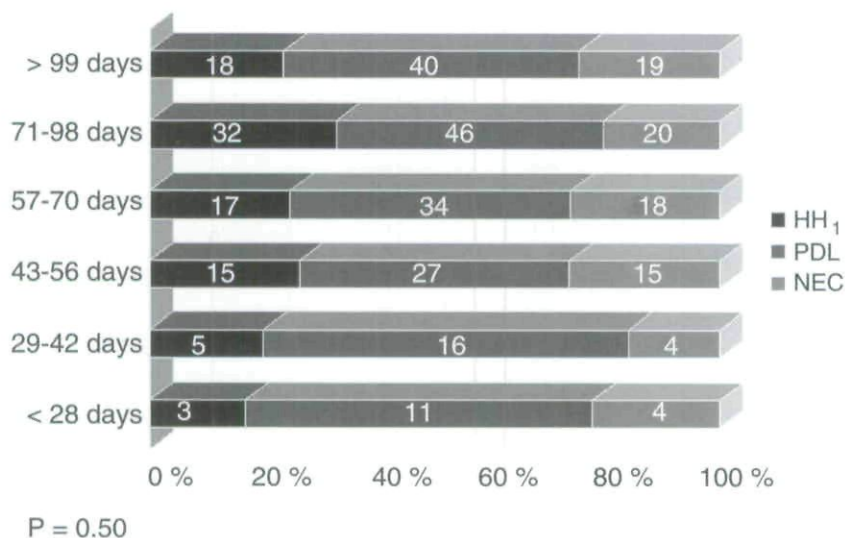


Fig. 7. Fixation duration related to healing. HH₁, healing with hard tissue between fragments; PDL, periodontal ligaments; NEC, pulp necrosis.

Splinting

Splinting was of special interest in this study, as a variety of splinting procedures had been introduced over the years. The aim of the splinting procedure was usually absolute immobility in traumatized region (8). In nature, wound healing is not normally associated with absolute immobility between the injured tissue surfaces. After a trauma, the pain reaction resulting from the injury implies restricted function, which in case of luxated teeth implies limited occlusal load. A splinting procedure, therefore, implies disturbance of natural healing events due to its restriction of mobility between the injured surfaces. This immobilization may result in reduced circulation. Thus, splinting in case of a luxation injury will result in marked immobility (e.g. cap splints, acid etch splints using composite resin) or restricted mobility (resin materials).

Wound healing processes in a number of tissues have been shown to be enhanced in situations with restricted mobility compared with complete immobilization. Such a relation has thus been established for skin (9), bone (10–13), cartilage (14), and tendons (15–17). In case of traumatic dental injuries, a more rapid PDL healing response (as indicated by greater PDL strength) was found in an experimental study of healing events after tooth replantation in monkeys in non-splinted teeth compared with splinted teeth (18).

In previous studies, splinting appeared to be significantly associated with the healing outcome after root fractures. Thus, it appeared that no splinting compared with rigid splinting (cap splints) gave a preference to hard tissue healing (2); while orthodontic band/acrylic fixation gave a preference to pulp necrosis compared with a traumatically applied acid-etched splints (5). In the present study, a number of alternative splinting procedures were used in the treatment of root fractures. Each of these splinting procedures implies at least three different healing scenarios to the periodontium and the pulp during splint application:

- additional trauma during splint application
- risk of bacterial invasion in the PDL due to the close proximity of the splint to the gingival wound and impaired oral hygiene
- restricted movement of the luxated coronal fragment

The net result of these three effects possibly explains the findings in this study, when splinting types were compared with their effect on root fracture healing.

In the present study, five different splinting techniques were compared for their capacity to influence hard tissue healing between fragments and pulpal healing vs. pulp necrosis. In the univariate and stratified analyses, it became apparent that the use of cap splints led to increased frequency of pulp necrosis. This might be related to the additional trauma derived from impression taking and cementation of the cap splint. Furthermore, the absolute rigidity of this splint could also have a detrimental effect on healing and furthermore also the impaired oral hygiene. The optimal splint in the present study was found to be the fiber glass/Kevlar® splint. This splint has been found *in vitro* experiments to be slightly flexible and application implies minimal handling of the injured tooth (G. Tsilingaridis, unpublished data).

The positive effect of no splinting of root-fractured teeth compared with a number of splinting types should be interpreted with caution, as the cases where no splinting was carried out were instances where there was no displacement of the coronal fragment. When the non-splinting group was matched with a similar splinted group (i.e. splinting, but no displacement or radiographically visible diastasis between fragments), there was no significant difference in healing. This implies that splinting and no splinting do not relate to healing in non-displaced teeth (Tables 6 and 7). With respect to displaced teeth, too few teeth were available to permit statistical analysis.

Table 6. Comparison between healing of non-splinted and splinted teeth with no dislocation or no diastasis from main material

	Healing type				Significance			
	1 (%)	2 + 3 (%)	4 (%)	n	HH ₁	PDL	NEC	HEAL
No splinting and no dislocation	30 (54)	18 (32)	8 (14)	57	0.44	0.83	0.51	0.46
Splinting and no dislocation	23 (63)	10 (27)	3 (8)	36				
No splinting and no diastasis	27 (52)	16 (31)	8 (16)	51	0.19	0.03	0.24	0.05
Splinting and no diastasis	58 (41)	71 (50)	12 (9)	141				

HH₁, healing with hard tissue between fragments; PDL, periodontal ligament; NEC, pulp necrosis; HEAL, healing.

Table 7. Healing related to non-treated, late appearing cases and cases from main material without dislocation or diastasis and no splinting

	Healing type				Significance			
	1	2 + 3 (%)	4 (%)	n	HH ₁	PDL	NEC	HEAL
Non-treated	10 (22%)	34 (76)	1 (2)	45	0.004	0.002	0.14	0.006
No dislocation and no splinting	27 (52%)	16 (31)	8 (15)	51				

HH₁, healing with hard tissue between fragments; PDL, periodontal ligament; NEC, pulp necrosis; HEAL, healing.

Splinting period

Concerning the lack of relation between the lengths of splinting period, this finding might be explained by rapid healing of a PDL wound. Thus, in a clinical study of avulsed and replanted teeth, mobility became almost normal after 3–4 weeks (19). This might imply that splinting beyond this time is not necessary for root fractures in general. An exception could be fractures located in the cervical region, which usually are very mobile and might, therefore, require a longer splinting period to permit significant callus formation. For these cases, maybe 2–3 months' splinting is recommendable.

Treatment delay

The lack of a beneficial effect of early treatment after trauma is surprising; but is in accordance with previous studies (20, 21). No explanation can be given; but similar paradoxical effects have been found in a variety of dental injuries including crown fractures, concussions and subluxation; whereas luxation with displacement showed a certain time relation between time of treatment and healing outcome (20). Further studies are needed to investigate the effect of treatment delay upon pulp and periodontal healing, not only following root fractures, but also for other groups of dental injury.

Antibiotics

The slightly negative (but not significant) role of antibiotics upon pulp necrosis and hard tissue healing needs an explanation. The obvious consideration was that antibiotics were only administered in cases with severe injury. However, this assumption could not be verified. In a previous, clinical study of root fractures, where administration of antibiotics was found to result in a significant increase in NEC (5). Also in this study, no explanation could be found for this paradox or the theory that antibiotics were related to the severity of the trauma. Further studies are certainly indicated.

Conclusion

This study has shown that treatment delay of up to several days plays no significant role, optimal repositioning of root fractures with dislocation of the coronal fragment of up to 1 mm favors both healing with hard tissue and at the same time reduces the risk of pulp necrosis. Concerning splinting it appears that in non-displaced teeth, it did not appear to have any positive effect upon either hard tissue fusion of fragments or on pulp necrosis. In the case of teeth with displaced coronal fragments, the general effect of splinting could not be examined due to a limitation of cases, however, the most beneficial splint appeared

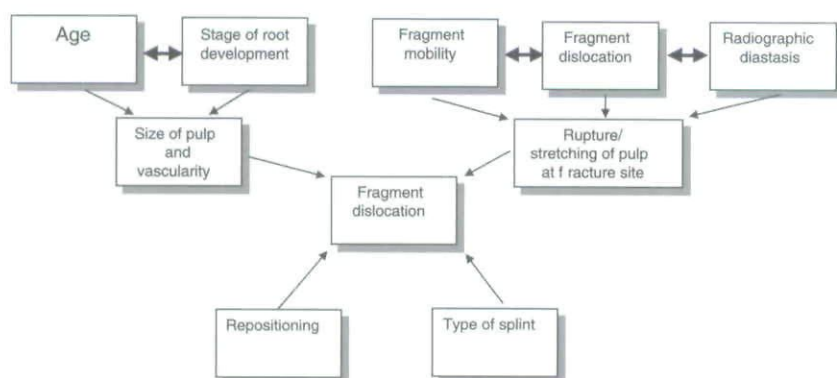


Fig. 8. Synopsis of pre- and post-injury factors related to root fracture healing.

to be a Kevlar[®] splint, which provides semi-rigid immobilization (Fig. 8). With the possible exception of cervical root fractures, which may require longer splinting periods, 4 weeks' splinting appears sufficient to ensure healing. Administration of antibiotics plays a questionable role in root fracture healing.

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