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Contradictions in the treatment of traumatic dental injuries and ways to proceed in dental trauma research*

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Abstract – Almost all treatment procedures used for dental traumas are still today not evidence-based, a fact, which makes it difficult to analyse the long-term outcome of healing and its relationship to treatment. *Crown fractures* with extensive dentin exposure represent a dominant injury in the permanent dentition. Accepted treatment philosophy is dentin coverage (dental liner and/or dentin bonded restoration) to prevent bacteria penetration into the pulp. Today there is, apart from deep proximal fractures, no evidence that this treatment is necessary to protect the pulp. In case of *luxation injuries*, the accepted treatment principles appear to be anatomically correct repositioning, stabilization with a splint and sometimes antibiotic coverage. In clinical studies, these principles could not be proven to optimize either periodontal or pulpal healing, the explanation possibly being that both reposition and application of splints in certain cases add extra damage to the pulp and periodontal ligament. In case of *root fractures* with dislocation, fast and optimal repositioning and rigid long-term splinting (i.e. 3 months) have been considered the principle of treatment. However, a recent clinical study has shown that short-term splinting with a semi-rigid splint appears to optimize fracture healing. In **tooth avulsion** with subsequent replantation, cleansing of the root surface for contamination and systemic antibiotics has been considered essential for pulp and periodontal healing. These treatment concepts have been derived from experimental studies in animals. However, their importance could not be verified in large clinical studies. Ideally, randomized clinical studies are needed in the future for selected trauma types. The influences of repositioning, splinting and the role of infection and antibiotics should be further investigated. However, for ethical reasons, it will be difficult to perform randomized studies on trauma victims and we will be forced in the future to rely on experimental animal studies supported by clinical observational studies.

The intriguing sentence 'Cognitive Dissonance' was used 40 years ago by S Seltzer and IB Bender in a thought-provoking article about the scientific foundation for clinical endodontics [Seltzer & Bender, (1)]. At that time, a dogmatic concept was that successful endodontic treatment rested on the premises that for the body to heal an apical pathosis related to an infected root canal, all bacteria in the root canal and surrounding tissues should be eliminated. This implied that all necrotic pulp tissue should be removed and a complete bacteria-tight root canal obturation should be performed. In the above-mentioned article, it was demonstrated that one or more of these dogmas could be violated and healing could still occur. This study started a series of investigations leading to a more sophisticated understanding of the balanced aggressor/host relationship in the root canal and periapical tissues as well as the healing potential in the apical periodontium (2).

In a recent analysis of the wound healing response after trauma, it became apparent that significant cognitive dissonance also exists in relation to treatment and dental trauma (3). Thus, the general principle for healing of crown fractures namely, to seal off exposed dentinal tubules as soon as possible with a lining material and/or restoration to ensure pulp survival was not an experimentally supported treatment principle (3). In fact, it is known that possibly only a minority of crown fractures today are treated by bacteria tight restorations if treatment is at all performed and still the pulp maintains vitality in almost all cases (4).

*Correction added after online publication 7 October, 2009. The title was originally published as "Cognitive dissonance in the treatment of traumatic dental injuries and ways to proceed in dental trauma research".

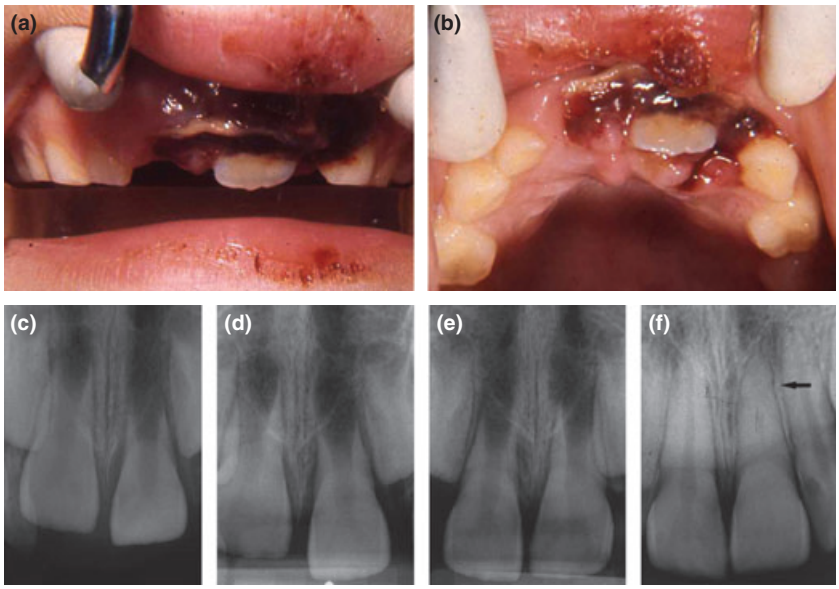

Fig. 1. Optimal pulp and periodontal ligament healing as well as root development after severe lateral luxation of a left central incisor. The tooth was displaced 3 mm in palatal direction. No repositioning or splinting was performed. (a, b) Frontal and axial appearance of injury site. (c, d) Occlusal and periapical exposure at the time of injury. (e) Spontaneous reposition is seen after 2 months. (f) Completed root development (see arrow) and partial pulp canal obliteration is seen at 5 years recall. The tooth responds to electrometric sensibility testing. No sign of root resorption.

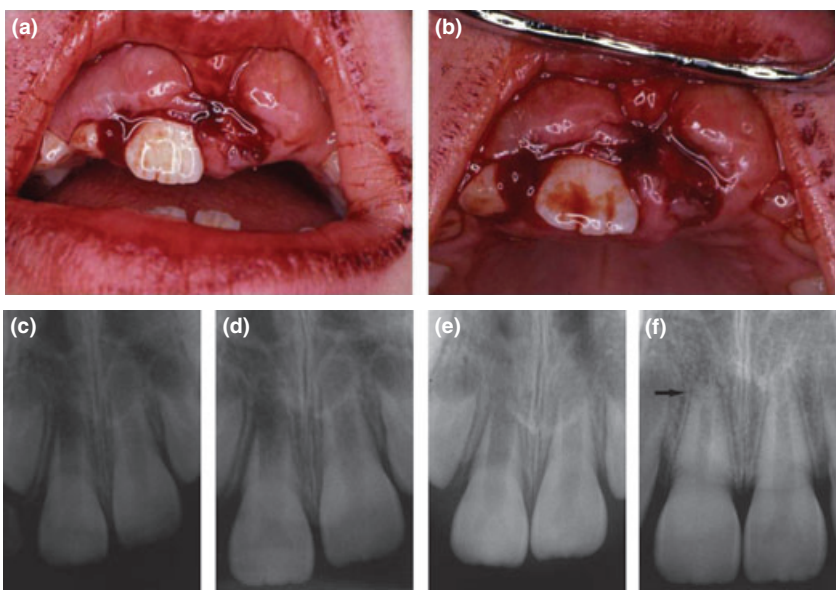

Fig. 2. Optimal pulp and periodontal ligament healing as well as root development after severe lateral luxation of a right central incisor. The tooth was displaced 3 mm in palatal direction. No repositioning or splinting was performed. (a, b) Frontal and axial appearance of injury site. (c, d) Occlusal and periapical exposure at the time of injury. (e) Spontaneous reposition is seen after 3 months. (f) Completed root development (see arrow) and partial pulp canal obliteration is seen at the one year control. The tooth responds to electrometric sensibility testing. No sign of root resorption.

Displaced, luxated or root fractured teeth suffer, for obvious reasons, extensive damage to both pulp and periodontium and accurate repositioning and splinting are considered a precondition for healing (5, 6). However, cases may occur where no treatment has resulted in good pulpal and periodontal ligament (PDL) healing (Figs 1 and 2). In case of tooth avulsions, optimal cleansing of the root surface for bacteria and other contaminants, quick replantation or storage in physiological medium before replantation and antibacterial coverage is considered essential (6). Still cases occurred where patients undertook the replantation themselves without proper cleansing and no antibiotics were given, and sometimes even no splinting was carried out and optimal healing still occurred (Fig. 3).

In the following, these healing scenarios will be described in more detail to elucidate the problems to find an explanation for these cognitive dissonances in healing principle for traumatized teeth.

Treatment of crown fractures

Epidemiology

Crown fractures are the most frequent injury in the permanent dentition and usually constitute 65–75% of all injuries affecting the permanent dentition (5, 7). Worldwide, it can be expected that most of these fractures will not be treated for economic reasons or for lack of manpower in dentistry (5, 8).

Treatment concepts

An enamel dental fracture will open up an extensive number of dentinal tubules (20–45 000 per.mm^2) (9),

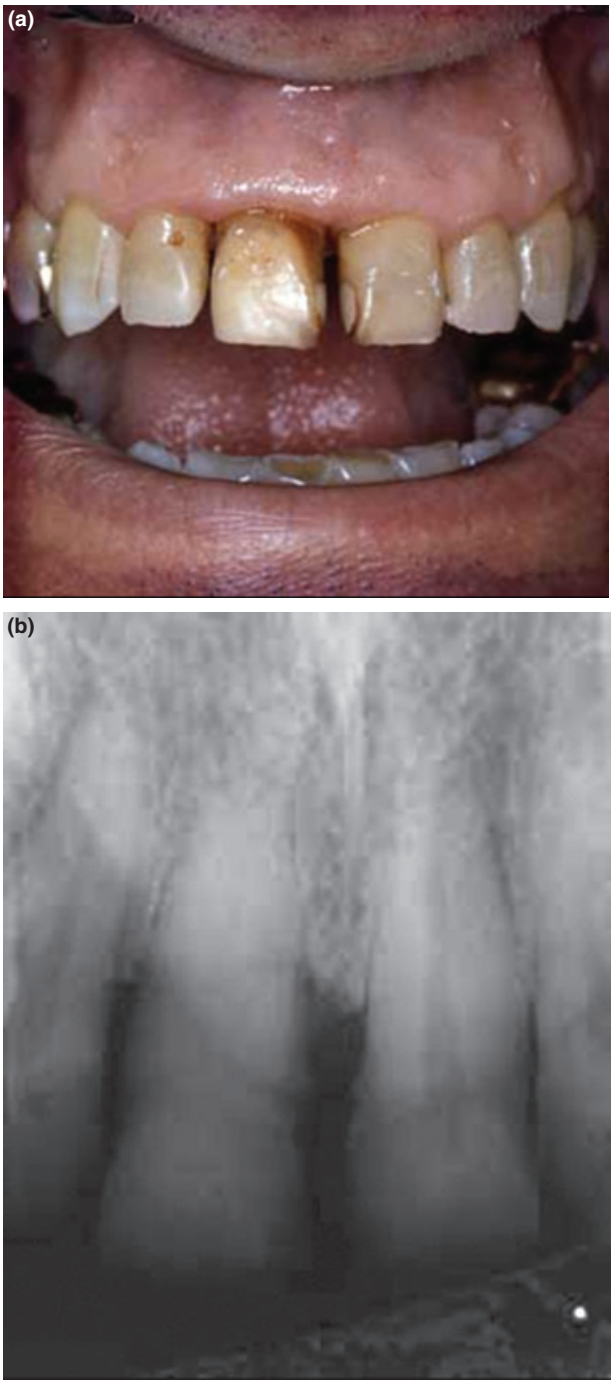

Fig. 3. A 52-year-old man who, as a boy, knocked out a right central incisor. He immediately grasped the incisor, which fell on the floor and replanted it without rinsing the tooth. A control radiograph after 44 years shows extensive root canal calcification and an intact periodontal ligament without signs of root resorption.

which allow penetration of oral bacteria into the dentinal tubules and thereby to the pulp (10). For this reason, exposed dentinal tubules need to be covered with a liner and/or restoration (usually an enamel and dentin bonded composite) to seal off bacteria to get into contact with exposed dentinal tubules (5, 6).

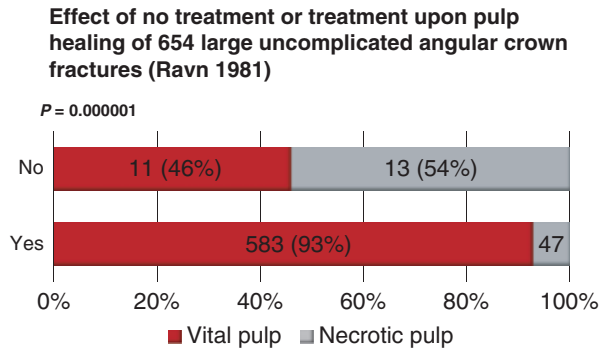

Fig. 4. Effect of treatment or no treatment upon pulpal healing after uncomplicated crown fractures with extensive proximal extension.

Clinical findings

In a single clinical study by Ravn (4), no effect of treatment (dentin coverage) was found for most types of enamel-dentin fractures. Only in case of deep proximal enamel-dentin fracture did no treatment lead to an augmented risk of necrosis (4) (Fig. 4).

Treatment contradictions

A trauma fracture exposure like attrition exposes a multitude of dentinal tubules. After a few days, a plaque is formed on the fractured surface and bacteria are found starting to invade dentinal tubules (10, 11). The exact speed and extent of this bacterial penetration are not known today. In one clinical study in humans in which artificial fractures were made in premolars, only a few dentinal tubules showed a superficial tubule invasion after 1 week. In a similar study where dentin was exposed by grinding, only superficial penetration took place (after 101 days) and bacterial invasion was limited to the outer third of the dentin (12). Unfortunately, in none of these studies associated pulp changes were described. Based on the above-mentioned clinical study [Ravn (4)], it might be assumed that bacterial penetration normally stops, but presently at which stage invasion of bacteria stops remains unknown.

The invasion of bacteria *in vitro* has been shown to depend upon the strain of bacteria and exposure time (13). It has been suspected that a positive pulp pressure may result in 'dentinal fluid flow' (14), which may mechanically inhibit invasion of bacteria through tubules. Such an effect has actually been demonstrated also in an *in vitro* study (10). In another *in vivo* study where class 5 cavities were prepared in mandibular third molars, bacteria showed faster and more extensive bacteria invasion in teeth with extirpated pulps compared with third molars with intact pulps (15), a finding which appears to support the importance of the 'dentinal fluid flow'.

We conclude that experiments need to be carried out where timing of bacterial invasion in dentinal tubules, including the extent of this and the associated pulp response, is analysed after fracture injuries.

Root fractures with displacement

Epidemiology

These are relatively rare injuries occurring with a frequency of 1–2% in the permanent dentition (5, 7).

Treatment concepts

An anatomically optimal repositioning and a rigid splint maintained for a long period (i.e. 3 months) have been suggested to optimize healing (16).

Clinical findings

In a recent large clinical study of 400 root-fractured permanent teeth, it was found that treatment delay up to several days had no influence upon healing (17). Furthermore, no splinting or flexible splinting was more favourable than rigid splinting. Finally, prolonged root fracture splinting (i.e. exceeding 1 month) did not advance healing (17).

Treatment contradictions

The concept of rigid and prolonged splinting originates from a concern about the stabilizing effect of the dentinal callus (17). From animal experimentation in dogs, it appears that a very tiny dentin callus is formed after 2 weeks (18). This finding indicated possibly a longer splinting period (16). However, in a clinical study in humans of avulsed and replanted teeth, the associated healing of the PDL is apparently very advanced after 2 weeks (19), a phenomenon which can possibly explain that the healing of the periodontium can take over the function of the splint at that time (20).

We conclude that there is a need for experimental studies to compare the tissue reaction and healing after experimental root fractures over time using various splinting times and the role of the localization of the root fracture should also be further studied.

Luxation injuries with displacement

Epidemiology

These are relatively common injuries occurring with a frequency of 8–20% among injuries affecting the permanent dentition (7). Again a certain amount of these cases will, for various reasons, not be treated and healing is still being found to occur (Figs 1 and 2).

Treatment concept

To ensure and facilitate wound healing in the pulp and periodontium, anatomically correct repositioning is necessary to reduce the distance between wound surfaces (6). Firm splinting is necessary to prevent or reduce movements between the healing tissues, which are supposed to have a detrimental effect upon healing (21). To control invasion of bacteria in the injured periodontium and pulp, antibiotics may prevent such infection complications.

Table 1. Effect of repositioning upon pulp healing after lateral luxation [Andreasen et al. (11)]

	Pulp healing	Pulp necrosis (%)
Complete repositioning	26	30 (54)
Incomplete repositioning	13	20 (61)
No repositioning	13	20 (61)

Probability levels:
**P = 0.73*

Table 2. Influence of splinting types after repositioning of lateral luxated teeth [Andreasen et al. (11)]

	Pulp survival	Pulp necrosis	%
Concise® (rigid splint)	10	15	60
Scutane® (flexible splint)	11	15	58
Orthodontic bands + acrylic	18	20	53
No splint	12	21	63

Probability levels:
**P = 0.82*

Table 3. Effect of antibiotics on periodontal healing of tooth luxation and root fractures

	Pulp survival	Pulp necrosis (%)
Luxation injuries[1]		
+ Antibiotics	47	26 (36)*
÷ Antibiotics	434	130 (23)
Root fractures[2]		
+ Antibiotics	8	5 (39)**
÷ Antibiotics	251	63 (20)
Root fractures[3]		
+ Antibiotics	4	7 (63)***
÷ Antibiotics	66	18 (21)

[1]Andreasen et al. (11)
[2]Andreasen et al. (17)
[3]Andreasen et al. (22)
Probability levels:
**P = 0.03*
***P = 0.15*
****P = 0.006*

Clinical findings

In a luxation study, no significant effect of optimal repositioning could be found in relation to pulp healing in non-repositioned teeth compared with repositioned teeth (22) (Table 1). Furthermore, splinting had no favourable effect upon healing (22) (Table 2). Finally, administration of antibiotics had a significant negative effect on periodontal healing in case of luxations and root fractures (17, 22) (Table 3).

Treatment contradictions

The lack of a beneficial effect of *repositioning* certainly calls for an explanation. First, the repositioning proce-

dure by it self, because of the necessary force used may, for obvious reasons, injure the PDL and pulp, especially in case of lateral luxation and intrusion (3).

Such an extra damage to the PDL cells on the root surface and pulp cells at the apical foramen may explain the added risk of pulp necrosis, root resorption and marginal healing complications [loss of gingival attachment] (3). Such an effect has actually been found when active repositioning (orthodontic or surgical) was performed in cases of intrusion of permanent teeth in comparison with no treatment (23). It may be argued that lack of repositioning may disturb healing of the pulp and periodontium because of the preserved distance between separated wound surfaces. However, recent experimental studies using a replant/transplant animal model have shown that such an event only leads to a few weeks' prolongation in pulp and periodontal healing, but not to a lack of healing (24).

The concept of splinting has, for decades, undergone several modifications. In the 1960s, rigid splinting using arch bars or cap splints and maintained for 3–6 months was considered essential for periodontal and pulpal healing (25). This concept was the state-of-the-art in many countries (26–30). In 1975, in an experimental study in monkeys, it was found that no splinting or 1 week splinting of replanted teeth had a better prognosis for PDL healing than rigid splinting for longer periods (31). In a later study, it was found that no splinting led to more optimal pulp healing in teeth with incomplete root formation at the time of replantation (32). In another experimental study in monkeys, it was found that masticatory stimulation after replantation reduced the extent of ankylosis (33).

The lack of effect of *splinting* (especially rigid) can have a dual explanation. First, several animal experiments have shown that slight mobility between wound surfaces favour both periodontal and pulpal healing (3, 34). Such an effect has also been found in a variety of other types of tissues such as those of the skin, tendons and bone for a survey [see Andreasen & Løwschall (3)]. Another parameter is that application and/or the physical presence of certain types of splint (e.g. arch bars fastened with cervical steel wires) may invite plaque accumulation and possibly bacterial invasion in the periodontal wound (34).

We conclude that there is a need for more experimental studies on repositioning and comparison of different splint types and splinting times and that clinical studies can verify the experimental findings

Tooth avulsion injuries with subsequent replantation

Epidemiology

These are relatively rare injuries occurring at frequency of 0.5–3% among injuries affecting the permanent dentition (5, 7).

Treatment concepts

The extra-oral time is considered critical for the result of replantation; therefore, prompt replantation is recommended (5, 35). Furthermore, proper rinsing of the tooth to eliminate or reduce contamination of the root surface and pulp before replantation, as well as antibiotic therapy, is considered essential (35).

Clinical findings

In a large clinical replantation study published by Andreasen et al. (36, 37), immediate replantation (usually performed by the patient himself or herself) usually implied that no rinsing took place and showed the most

Table 4. Relation between root surface contamination status of avulsed teeth. From Andreasen et al. (36)

Contamination	*n*	PDL resorption (%)
No	115	76 (64)
Yes	56	11 (81)

PDL, periodontal ligament.
Probability level:
**P = 0.01*

Table 5. Relationship between PDL healing resorption and root surface contamination status of avulsed teeth. From Kinirons et al. (39)

Contamination	Number	PDL resorption (%)
None	70	40 (57)
Washed clean	44	33 (75)
Rubbed clean	8	7 (88)
Replanted but not clean	6	6 (100)

PDL, periodontal ligament.
Probability level:
**P = 0.01*

Table 6. Relationship between pulp healing and administration of antibiotics after replantation of avulsed teeth [Andreasen et al. (36)]

	Pulp healing	Pulp necrosis (%)
+ Antibiotics	19	35 (65)
÷ Antibiotics	4	3 (43)

Significance level:
**P = 0.23.*

Table 7. Relationship between PDL healing and administration of antibiotics after replantation of avulsed teeth [Andreasen et al. (35)]

	PDL healing	Root resorption (%)
+ Antibiotics	49	153 (75)
÷ Antibiotics	20	49 (71)

Significance level:
PDL, periodontal ligament.
**P = 0.44*

favourable healing (3). In the same study, it was found that obvious contamination of root surface before replantation resulted in a higher risk of root resorption (Table 4) (36). Surprisingly enough, in another clinical study, rinsing of the root surface resulted in more root resorption (Table 5). The use of systemic antibiotics has been found, in a study in monkeys, to be able to improve PDL healing (38), whereas such an effect could not be found in humans (36).

The use of systemic antibiotics after replantation was not found to improve either pulp or periodontal healing in clinical studies (36, 37) (Tables 6 and 7).

Treatment contradictions

The lack of effect of optimal *rinsing* of the root surface in a clinical study (39) is in conflict with an experimental study in monkeys where just 10 s rinsing of the root surface was able to improve PDL healing (40). It seems difficult at this time to find an explanation for these contradictory findings apart from a possibility that any mechanical cleansing procedure may injure PDL cells on the root surface.

Finally, the effect of antibiotic coverage in the healing period is presently difficult to explain. In maxillofacial injuries, a recent systematic review of the use of antibiotics has demonstrated a significant reduction in the number of fracture line infections when antibiotics were used systemically (41). The topography of jaw fractures to the oral cavity, however, differs in some ways in relation to luxations and root fractures in the sense that the extent of injury to the PDL is usually more reduced in luxation injuries compared with jaw fractures. Furthermore, systemic-administered antibiotics may have problems in getting access at a therapeutic level in a severed pulp and/or PDL after luxation because of problems in diffusion (42).

We conclude that there is a need for more experimental and clinical studies on the role of infection and decontamination for replanted teeth.

Conclusion

In this perusal of the literature, it becomes apparent that in a majority of cases, standard treatment procedures such as dentin coverage, repositioning, splinting and antibiotics do not always optimize pulp and PDL healing. Treatment is therefore mainly performed to normalize occlusion and aesthetics. At present, treatment guidelines for traumatized teeth are not based on clinical randomized studies and a final evaluation of treatment effects is therefore not possible. Clinical randomized control studies on various treatment approaches are desirable. It should, however, be realized that the emergency situation in relation to acute trauma may prevent the performance of such studies. It is hardly ethically correct to ask for an informed consent from a traumatized patient to participate in such a study. It is therefore of importance that existing treatment guidelines are based on the rather few randomized experimental studies in animals and that there are more such studies performed. Furthermore, more prospective clinical observational studies are needed whether or not the treatment variable in question appears to be supported by the clinical findings.

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