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Combination injuries 3. The risk of pulp necrosis in permanent teeth with extrusion or lateral luxation and concomitant crown fractures without pulp exposure

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Abstract – *Aim*: To analyze the influence of a crown fracture without pulp exposure on the risk of pulp necrosis (PN) in teeth with extrusion or lateral luxation. *Material and methods*: The study included 82 permanent incisors with extrusion from 78 patients (57 male, 21 female) and 179 permanent incisors with lateral luxation from 149 patients (87 male, 62 female). A total of 25 teeth with extrusion and 33 teeth with lateral luxation had suffered a concomitant crown fracture (infraction, enamel fracture or enamel-dentin-fracture). All the teeth were examined and treated according to a standardized protocol. *Statistics*: The risk of PN was analyzed separately for teeth with immature and mature root development by the Kaplan–Meier method, the log-rank test and Cox regression (lateral luxation only). The level of significance was set at 5%. Risk factors included in the analysis were gender, age, crown fracture, and response to electric pulp test at the initial examination. *Results*: A concomitant crown fracture significantly increased the risk of PN in teeth with lateral luxation. For teeth with immature root development (hazard ratio: 10 [95% confidence interval (CI): 1.1–100] $P = 0.04$), the overall risk increased from 4.7% (95% CI: 0–10.8) to 40% (95% CI: 2.8–77.2). For teeth with mature root development [hazard ratio: 2.4 (95% CI: 1.4–4.2) $P < 0.001$], the overall risk increased from 65.1% (95% CI: 55.2–75.1) to 93% (95% CI: 85.5–100). In teeth with *extrusion and mature root development*, the overall risk of PN increased from 56.5% (95% CI: 37.7–75.4) to 76.5% (95% CI: 58.9–94) in case of a concomitant crown fracture, but the difference was not statistically significant ($P > 0.05$). *Conclusion*: A concomitant crown fracture without pulp exposure significantly increased the risk of PN in teeth with lateral luxation. This risk factor may be used to identify teeth at increased risk of PN following lateral luxation injury.

Pulp necrosis (PN) is a frequent complication in teeth with extrusion or lateral luxation injuries (1–4). When a dental trauma results in an *extrusion* of a tooth, an almost total severance of the periodontal ligament occurs. The trauma involves a high risk of disruption of the neurovascular supply at the apex of the tooth which causes pulp infarction. In a *lateral luxation*, the trauma is further complicated by a fracture of the labial bone and compression of the tissue in the apical and cervical areas of the tooth (5). Healing will imply reorganization and reestablishment of the periodontal fibers and pulpal revascularization and re-innervation. In teeth with immature root development, this can either occur by in-growth of new blood vessels into the pulp chamber or by end-to-end anastomoses of the blood vessels in the apical area (1, 6). For teeth with mature root development, this healing process is affected by the small contact area between the ischemic pulp tissue and the periodontal tissue (7). Multivariate analyses have shown that the stage of root development and the type of luxation are the most important factors influencing pulp healing in teeth with luxation injury (1). However, pulp healing is critically dependent on the absence of bacteria (8, 9). The presence of bacteria in the root canal has been reported to be the principle cause of pulp revascularization failure (10). Hence, successful pulp healing probably depends on the balance between reestablishing the blood supply and thereby the defense of the pulp and the constant risk of bacterial invasion into the non-vascularized part of the pulp. A crown fracture with exposed dentinal tubules may represent a way for bacteria to gain access to the injured pulp (8, 11). In the accompanying reports a concomitant crown fracture significantly increased the risk of PN in teeth with concussion or

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subluxation (12, 13). Therefore, it was hypothesized that teeth with an *extrusion* or a *lateral luxation* injury and a concomitant crown fracture would have a higher risk of PN than teeth with an extrusion or a lateral luxation injury only, due to an increased likelihood of bacterial invasion via the fracture site. To our knowledge no previous studies have analyzed this issue.

A combination injury caused by dental trauma represents a complex healing scenario and the risk of PN is influenced, among others, by the degree of displacement in teeth with extrusion (14) and by a negative reaction to electric pulp test (EPT) at the initial examination in teeth with lateral luxation (1). These factors should be taken into consideration when assessing the prognosis of the pulp. The aim of this study was to analyze the influence of a crown fracture without pulp exposure on the risk of PN in teeth with extrusion or lateral luxation injuries.

Material and methods

The material included patients treated at the Department of Oral and Maxillo-Facial Surgery, Copenhagen University Hospital, Rigshospitalet, Denmark in the period 1973–1989.

Patients were included into the study if the following criteria were fulfilled:

1 The tooth had suffered either an *extrusion* or a *lateral luxation* injury. *Extrusion* was defined as an injury to the tooth characterized by partial or total separation of the periodontal ligament resulting in loosening and displacement of the tooth in an axial direction. *Lateral luxation* was defined as an injury to the tooth characterized by partial or total separation of the periodontal ligament combined with a fracture of either labial or palatal/lingual bone where the tooth is displaced in a direction other than axially.

2 The tooth did not have a crown fracture with pulp exposure.

3 Tooth-specific clinical information and radiographs from the initial examination and the subsequent controls according to a standardized protocol were present.

4 Clinical photographs from the time of injury were present.

5 A follow-up period of minimum 300 days.

6 The tooth had no previous trauma.

7 No severe destruction of the crown caused by dental caries or restorations.

The standard follow-up program included controls at 3, 6 weeks, 6 months, 1 and 5 years. The follow-up period ranged from 331 days (11 months) to 5651 days (15.5 years) with a median of 446 days (1.2 years).

Clinical registrations

At the time of the injury, the following parameters were registered on a special trauma chart: gender, age, cause of injury, date and time of injury, number of injured teeth, the condition of the supporting tissue, and fractures of the teeth. Crown fractures were defined as trauma-related infraction, enamel fracture, and enamel-dentin fracture, according to a modification of the WHO definition (13, 15). For each tooth, clinical information from the time of injury and from follow-up examinations was recorded using a standardized form including: tooth color, tenderness to percussion, mobility, and displacement of the tooth (16).

EPT was performed using a Sirotest II®; pulp tester (Siemens, Munich, Germany) (scale 0–4) placed on the incisal edge of the tooth. The test was performed at the initial examination and at follow-up examinations (16).

Horizontal and axial photographs were taken at the time of injury. Three periapical radiographs (ortho-, mesio-, and distoradial/angulation) and an occlusal exposure were taken at the initial examination. At the follow-up controls, a periapical exposure was taken (16).

The stage of root development was determined by evaluation of radiographs from the initial examination and classified into one of the following six stages described by Moorrees et al. (17): 1: ¼ root formation, 2: ½ root formation; 3: 3/4 root formation; 4: full root formation with wide-open apex; 5: full root formation with ½ closed apex; 6: full root formation with closed apex. The material in the present study was divided into two subgroups: immature root development stages 1–5 and mature root development stage 6.

Treatment

The treatment of the crown fractures was performed according to a predefined protocol previously described (13). The displaced teeth were manually repositioned and splinted to the neighboring teeth. Splinting was performed either using orthodontic bands and Paladur® (Heraeus Kulzer, Hanau, Germany) or using acid-etch and a flexible temporization material (Scutan® or Protemp®; 3M ESPE, Seefeld, Germany).

Pulp necrosis

PN was diagnosed if two of the following clinical signs were present:

1 Grey discoloration of the crown.

2 Periapical radiolucency.

3 No response to EPT after 3 months of observation.

Statistical methods

The material in the present study was divided into two subgroups (teeth with immature and teeth with mature root development) and analyzed separately.

In teeth where PN was diagnosed in the period until 800 days after the injury, we approximated the PN onset time as the midpoint between the date of the first examination where PN was diagnosed and the date of the last examination where the tooth in question was not diagnosed with PN. For the remaining teeth, PN was not diagnosed in the period until 800 days after the injury (13).

The overall risk of PN within the first year after the injury was analyzed using the Kaplan–Meier method (18, 19). Exact binomial confidence limits were computed for subgroups with no observed cases of PN based on the number of teeth followed for at least 1 year.

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Table 1. Characteristics of patients (age, gender, number of injured teeth in each patient) and teeth [type of crown fracture, response to electric pulp test (EPT) at the initial examination, treatment delay] in relation to stage of root development for teeth with extrusion

	Immature root development	Mature root development	Total
	No. patients (%)	No. patients (%)	No. patients (%)
Gender			
Female	12 (30.8)	9 (23.1)	21 (26.9)
Male	27 (69.3)	30 (76.9)	57 (73.1)
Age (years)			
<20	39 (100.0)	32 (82.1)	71 (91.0)
≥20	0 (0.0)	7 (17.9)	7 (9.0)
Number of injured teeth in each patient			
One	6 (15.4)	5 (12.8)	11 (14.1)
Two	17 (43.6)	12 (30.8)	29 (37.2)
Three or more	16 (41.0)	22 (56.4)	38 (48.7)
	No. teeth (%)	No. teeth (%)	No. teeth (%)
Crown fracture type			
No fracture	34 (81.0)	23 (57.5)	57 (69.5)
Infraction	1 (2.4)	5 (12.5)	6 (7.3)
Enamel fracture	4 (9.5)	2 (5.0)	6 (7.3)
Enamel-dentin fracture	3 (7.1)	10 (25.0)	13 (15.9)
EPT at the initial examination			
No response	29 (69.0)	35 (87.5)	64 (78.0)
Response	7 (16.7)	2 (5.0)	9 (11.0)
Unknown	6 (14.3)	3 (7.5)	9 (11.0)
Treatment delay[1] (h)			
<5	33 (89.2)	33 (91.7)	66 (90.4)
5–24	3 (8.1)	3 (8.3)	6 (8.2)
More than 24	1 (2.7)	0 (0.0)	1 (1.4)

EPT, electric pulp test.
[1]Information of treatment delay is available for 73 teeth.

Table 2. Characteristics of patients (age, gender, number of injured teeth in each patient) and teeth [type of crown fracture, response to electric pulp test (EPT) at the initial examination, treatment delay] in relation to stage of root development in teeth with lateral luxation

	Immature root development	Mature root development	Total
	No. patients (%)	No. patients (%)	No. patients (%)
Gender			
Female	18 (45.0)	44 (40.4)	62 (41.6)
Male	22 (55.0)	65 (59.6)	87 (58.4)
Age (years)			
<20	40 (100.0)	73 (67.0)	113 (75.8)
≥20	0 (0.0)	36 (33.0)	36 (24.2)
Number of injured teeth in each patient			
One	11 (27.5)	14 (12.8)	25 (16.8)
Two	19 (47.5)	42 (38.5)	61 (40.9)
Three or more	10 (25.0)	53 (48.6)	63 (42.3)
	No. teeth (%)	No. teeth (%)	No. teeth (%)
Crown fracture type			
No fracture	43 (89.6)	103 (78.6)	146 (81.6)
Infraction	0 (0.0)	8 (6.1)	8 (4.5)
Enamel fracture	3 (6.3)	7 (5.3)	10 (5.6)
Enamel-dentin fracture	2 (4.2)	13 (9.9)	15 (8.4)
EPT at the initial examination			
No response	34 (70.8)	110 (84.0)	144 (80.4)
Response	5 (10.4)	7 (5.3)	12 (6.8)
Unknown	9 (18.8)	14 (10.7)	23 (12.8)
Treatment delay[1] (h)			
<5	30 (90.9)	87 (80.6)	117 (83.0)
5–24	3 (9.1)	18 (16.7)	21 (14.9)
More than 24	0 (0.0)	3 (2.8)	3 (2.1)

EPT, electric pulp test.
[1]Information of treatment delay was available for 141 teeth.

Changes in the risk of PN due to a concomitant crown fracture were assessed by the log-rank test (teeth with extrusions) and Cox regression analysis (teeth with lateral luxation). Further risk factors in the Cox regression were gender, patient age, and EPT outcome, in the analysis of mature teeth, and the stage of root development (stage 1–5) in the analysis of immature teeth. Robust confidence limits and *P*-values were obtained to account for the dependencies of teeth placed in the same patients (19). All analyses were performed with the statistical software R. (R development core team, Vienna, Austria) (20).

Results

A total of 261 permanent incisors from 227 patients (144 male and 83 female) fulfilled the inclusion criteria. A total of 82 teeth had suffered an extrusion injury and 179 had suffered a lateral luxation injury. A total of 25 teeth with extrusion and 33 teeth with lateral luxation had suffered a concomitant crown fracture (infraction, enamel fracture, or enamel-dentin-fracture). The distributions of gender, patients age, number of injured teeth per patient, type of crown fracture, and the response to EPT at the initial examination are given in Table 1 (extrusion) and Table 2 (lateral luxation). Data are given for the group of teeth with immature and mature root development, respectively.

Information about the time that passed between when the injury occurred and when treatment was performed, was available in 73 teeth with extrusion and 141 teeth with lateral luxation. The treatment delay ranged from 65 min to 82 h with a mean of 4.6 h. The majority of the teeth were treated within the first 5 h (Tables 1 and 2).

Extrusion

Among teeth with immature root development, two teeth without concomitant crown fracture developed PN (risk of PN after 1 year: 5.9% [95% confidence limits (CI): 0–13.6]). There was no significant difference between the risk of PN in teeth with a crown fracture and teeth without a crown fracture ($P > 0.05$).

For teeth with mature root development and extrusion, the risk of PN after 12 months increased from 56.5% (95% CI: 37.7–75.4) to 76.5% (95% CI: 58.9–94) if the tooth had a concomitant crown fracture (Table 3, Fig. 1). The difference was not statistically significant ($P > 0.05$).

Lateral luxation

Among teeth with immature root development and lateral luxation, the overall risk of PN within the first 12 months after the injury increased from 4.7% (95%

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Table 3. Risk of pulp necrosis (PN) after 1 year (Kaplan–Meier estimate) for teeth with extrusion and lateral luxation. The risk is estimated for teeth with and without a concomitant crown fracture in relation to stage of root development

	Immature root development					Mature root development				
	Teeth at injury[1]	Teeth lost to follow-up[2]	Teeth with PN[3]	Risk of PN[4] (%)	95% CI	Teeth at injury[1]	Teeth lost to follow-up[2]	Teeth with PN[3]	Risk of PN[4] (%)	95% CI
Extrusion and no crown fracture	34	5	2	5.9	(0–13.6)	23	2	13	56.5	(37.7–75.4)
Extrusion and crown fracture	8	2	0	0	(0–45.9)	17	0	13	76.5	(58.9–94.0)
Lateral luxation and no crown fracture	43	8	2	4.7	(0–10.8)	103	7	67	65.1	(55.2–75.1)
Lateral luxation and crown fracture	5	0	2	40.0	(2.8–77.2)	28	0	26	93	(85.5–100.0)

CI, confidence intervals.
[1]Number of teeth at the beginning of the study.
[2]Teeth lost to follow-up within the first year.
[3]Number of teeth diagnosed with PN within the first year.
[4]Risk of PN estimated after 1 year.

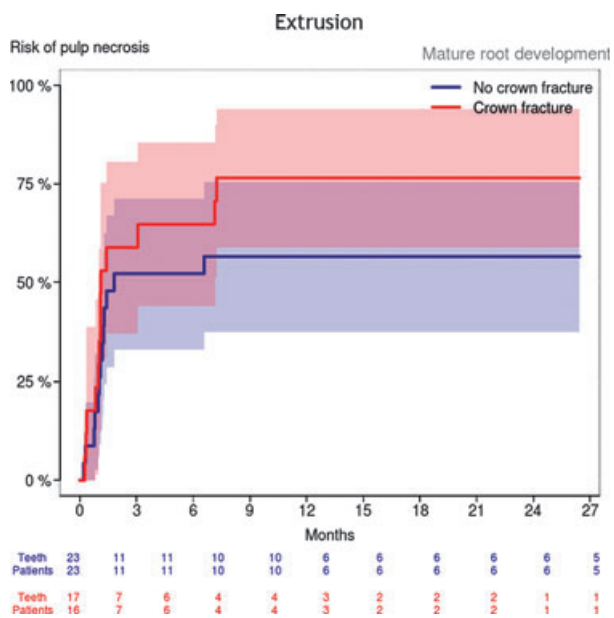

Fig. 1. The risk of pulp necrosis for teeth with extrusion and mature root development with and without concomitant crown fracture. The shaded area represents 95% confidence intervals.

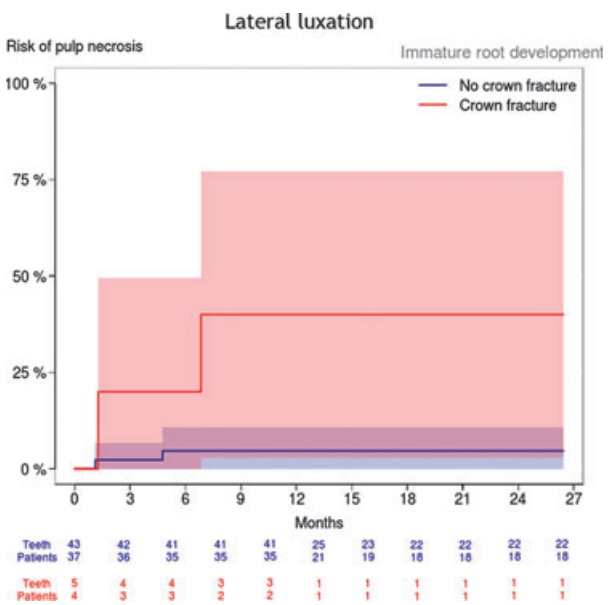

Fig. 2. The risk of pulp necrosis for teeth with lateral luxation and immature root development with and without a concomitant crown fracture. The shaded area represents 95% confidence intervals.

Table 4. Cox regression analysis of teeth with lateral luxation and immature root development

	Hazard ratio	95% confidence intervals	*P* value
No crown fracture	Ref.group	–	–
Crown fracture without pulp exposure	10.0	(1.1–100)	0.04
Stage of root development (1–5)	0.96	(0.2–4.8)	0.96

CI: 0–10.8) to 40% (95% CI: 2.8–77.2) if the tooth had a concomitant crown fracture (Table 4). Figure 2 shows the development of the risk of PN over time for teeth with and without a concomitant crown fracture. The Cox regression analysis (Table 4) showed that the risk of PN was significantly higher if the tooth had a concomitant crown fracture (hazard ratio: 10, 95% CI: 1.1–100, $P = 0.04$). No statistical association was found between increasing stages of root development (stage 1–5) and PN.

Among teeth with mature root development and lateral luxation, the overall risk of PN within the first 12 months after the injury increased from 65.1% (95% CI: 55.2–75.1) to 93% (85.5–100) if the tooth had a concomitant crown fracture (Table 3). Figure 3 shows the development of the risk of PN over time for teeth (mature root development) with and without concomitant crown fracture.

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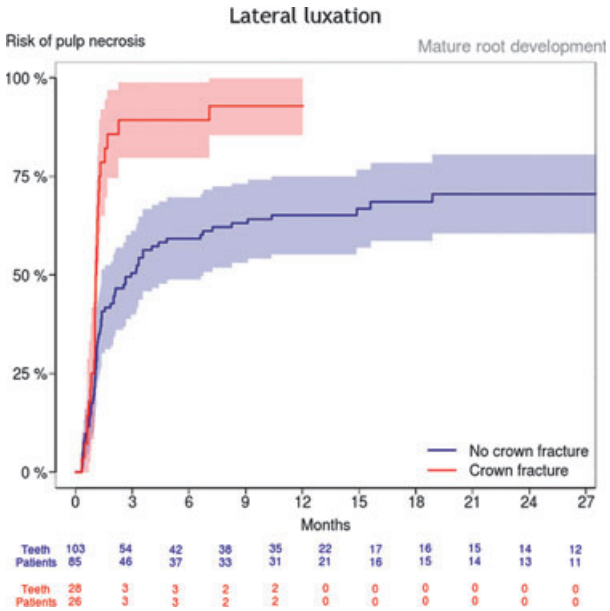

Fig. 3. The risk of pulp necrosis for teeth with lateral luxation and mature root development with and without a concomitant crown fracture. The shaded area represents 95% confidence intervals.

The Cox regression analysis (Table 5) showed that the risk of PN was significantly higher for teeth with crown fracture than for teeth without a crown fracture [hazard ratio: 2.4 (95% CI: 1.4–4.2), $P < 0.001$]. Gender, age, and the result of the EPT at the initial examination were not statistically associated with PN in teeth with mature root development ($P > 0.05$).

Discussion

Trauma-related factors

Crown fractures

A concomitant crown fracture without pulp involvement significantly increased the risk of PN in teeth with *lateral luxation*. This result supports the hypothesis, that in case of a concomitant crown fracture the risk of PN will be increased due to an increased risk of bacterial penetration through exposed dentinal tubules. However, for teeth with *immature* root development and *lateral luxation* (Fig. 2), the very large confidence intervals indicate that a larger sample size is required for a more accurate result. The hypothesis was based on the assumption that bacteria can penetrate the crown of the tooth through defects in the enamel and affect the healing of the partially or totally ischemic pulp tissue. This issue has been discussed in an accompanying report (12).

Table 5. Cox regression analysis of teeth with lateral luxation and mature root development

	Hazard ratio	95% confidence intervals	*P* value
No crown fracture	Ref.group	–	–
Crown fracture without pulp exposure	2.4	(1.4–4.2)	0.0008
Response to EPT	Ref.group	–	–
No response to EPT	2.1	(0.7–6.7)	0.21
Female	Ref.group	–	–
Male	0.9	(0.6–1.5)	0.82
Age <20 years	Ref.group	–	–
Age	0.9	(0.6–1.6)	0.80

EPT, electric pulp test at the initial examination.

It has been suggested that bacteria may enter the pulp via other pathways as well. If the periodontal ligament is injured, bacteria can progress through the coagulum in the separation site in the periodontal ligament; settle on the root surface, and gain access to the pulp canal through lateral canals or the apical foramen (8). However, this route of bacterial penetration into the periodontal ligament in traumatized teeth has never been tested experimentally. Anachoresis, which describes a situation where the necrotic tissue becomes infected by bacteria in the blood stream, has also been suggested as a source of bacterial infection (21–23). Bacteremia occurs periodically in all individuals and the bacterial origin is often the marginal periodontium (24). Bacteria injected into the blood stream have been identified in damaged pulp tissue in experimental animal studies (21–23). The actual frequency of bacteria using the three different pathways is presently not known. However, the increased risk of PN in teeth with a concomitant crown fracture found in this study may be an estimate of the role of crown fractures as a path way for bacterial penetration.

Type of crown fracture

Due to the limited sample size, three different crown fracture types (infraction, enamel fracture, enamel-dentin fracture) were grouped in one category in the analysis. However, it is likely that these three fracture types will affect the risk of PN differently as has been shown in teeth with subluxation injury (12). Furthermore studies are required to estimate the risk of PN for each of the different crown fracture types when they occur in combination with an extrusion or a lateral luxation.

Degree of displacement and EPT at the initial examination

In a previous study of factors affecting the risk of PN in teeth with extrusion, it was found that an extrusion exceeding 3 mm significantly increased the risk of PN (14). This probably reflects the different healing scenarios of a partly and completely severed neurovascular supply. In the present study, it was not possible to perform multivariate analysis due to the limited size of the sample of teeth with extrusion and it was therefore not possible to account for this possible risk factor. In teeth with lateral luxation, the displacement of the tooth occurs in two dimensions, i.e. both the horizontal and the vertical plane. It is accordingly difficult to use the degree of displacement as an expression of the severity of the trauma and the extent of the injury to the neurovascular supply. Instead, the response to the EPT at the initial examination was used. No response to EPT was not significantly related to subsequent PN. Only few

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teeth responded to the test (Table 2). The EPT at the initial examination is therefore not a suitable tool for identifying teeth with an increased risk of PN following extrusion and lateral luxation injuries.

Patient-related factors

Stage of root development

When the neuro-vascular supply is severed at the apical foramen due to trauma, pulp healing will imply pulpal revascularization and re-innervation. In teeth with immature root development, this can either occur by end-to-end anastomoses of the blood vessels in the apical area or by in-growth of new blood vessels into the pulp chamber. Skoglund et al. (6) investigated this event in an experimental study in dogs. They found evidence of blood flow in 20% of the replanted teeth already after 4 days as a result of end-to-end anastomoses of vessels in the socket and vessels in the pulp. In other teeth, a gradual in-growth of vessels took place, and full revascularization was established after 30 days. For teeth with mature root development, this healing process is highly affected by the minor contact area between the ischemic pulp tissue and the periodontal tissue. Andreasen et al. (1, 7) analyzed the influence of the size of the apical foramen on the development of PN in teeth with luxation injuries. The authors concluded that the stage of root development and the type of luxation were the most important factors influencing pulp prognosis. Hence, the size of the apical foramen may reflect the healing potential of the pulp (1). Teeth with mature and immature root development were therefore analyzed separately to minimize the variance of the material. However, among teeth with lateral luxation and *immature* root development, the effect of increasing stages of root development (stage 1–5) on the risk of PN was analyzed. No significant association was found. This result is not in agreement with results from a previous report analyzing teeth with subluxation injury and immature root development (12) and may be due to a limited number of teeth with lateral luxation and immature root development.

Age of the patient

No association was found between increasing patient age and the risk of PN in the multivariate analysis. This may be due to the low number of older patients in the study (Tables 1 and 2).

Treatment-related factors

The present study was not designed to estimate the effect of different treatment modalities. Generally, the teeth were treated according to predefined principles. The majority of the patients were received at the emergency clinic within the first five h after the trauma had occurred (Tables 1 and 2). Therefore, treatment delay was not included as a risk factor in the analysis. Further studies are required to analyze the influence of delayed treatment on the risk of PN in teeth with combination injuries. However, based on existing knowledge (25) and the results of this study, it is recommended that crown fractures be restored and infractions sealed as soon as possible to reduce the risk of PN in teeth with extrusion and lateral luxation.

Conclusion

The presence of a crown fracture without pulp exposure significantly increased the risk of PN in teeth with lateral luxation. It is likely that a concomitant crown fracture will have a similar effect on teeth with extrusion, but a larger sample size is required to analyze this effect. Based on the results of the present study, it is recommended that crown fractures in teeth with extrusion and lateral luxation be restored and infractions sealed as soon as possible to reduce the risk of PN.

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