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Outcomes of dental fracture injury as related to laser Doppler flow measurements of pulpal blood-flow level

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Abstract – Laser Doppler flowmetry (LDF) is a non-invasive method to assess pulpal blood flow (PBF). Dental fracture injuries have been associated with significant PBF reduction The purpose of this study was: (i) to evaluate whether the severity of outcomes of dental fracture injuries may be related to LDF measurements of PBF, and (ii) to investigate whether outcomes of dental fracture injuries may predict PBF levels. The relationship between outcomes and PBF measurements was analyzed in 72 permanent maxillary incisors of 52 consecutive dental trauma patients. The diagnostic outcome group comprised 72 incisors with a type I (absence of sensitivity, periapical radiolucency, and grey discoloration of crown) ($n = 42$), type II (loss of sensitivity) ($n = 16$), or type III (loss of sensitivity, periapical radiolucency, and/or grey discoloration of crown) diagnosis. At each session, when an injured permanent maxillary incisor was recorded, a contralateral homologous tooth was used as a control. An ordinal stepwise regression was completed to assess the degree of association between PBF measurements and diagnostic outcomes. A logistic regression analysis was used to compute the odds ratios for the outcome features for incisor non-injury controls vs two outcome groups: type II ($n = 16$) and type III ($n = 14$). PBF measurements that were significantly associated with more severe outcome were PBF levels of ≤6 perfusion units (PU) (106.70 odds ratio) ($P = 0.000$). Significant increase in the risk of a PBF level of ≤6 PU occurred with a type III outcome (32.49 odds ratio) ($P = 0.004$). PBF measurements were related to the severity of adverse outcomes. Diagnoses of treatment outcomes predicted the presence of specific PBF levels.

Several studies showed that in the permanent dentition dental injuries of crown (1–3) and root fractures (2, 4) are more common than those of luxations. Crown fractures may be uncomplicated involving enamel and dentin, or complicated, involving pulp (5). Root fracture is a combined injury of pulp, dentin, cementum, and periodontal ligament and is a relatively uncommon type of dental trauma (5, 6). Treatment outcome of fractured teeth may be influenced by several factors, such as degree of dislocation, concomitant dento-alveolar injuries, stage of root formation, time period between trauma and treatment, and type of dental trauma splint. If the tooth becomes necrotic and infected, an external inflammatory root resorption may occur, which may result in tooth loss within a short period (7). In teeth with incomplete root formation, circulation survival and revascularization is possible and highly desirable, not only to maintain an infection-free pulp space, but to allow the tooth to continue to develop and strengthen (8, 9).

Several authors reported the use of flowmetric values to demonstrate the reestablishment of vitality in traumatized teeth (10–15). In instances of dental trauma, Laser Doppler flowmetry (LDF) may be useful in the detection of transient ischemic episodes and the identification of teeth at risk for adverse outcomes such as avascular necrosis and tissue loss (16–18). The purpose of this study was to: (i) evaluate whether the severity of outcomes of dental fracture injuries may be related to LDF measurements of pulpal blood flow (PBF), and (ii) investigate whether outcomes of dental fracture injuries may predict PBF levels.

Materials and methods

Subjects

The study group of 52 patients undergoing dental trauma splinting included 17 females and 35 males, with a mean age of 25 years (range, 15–29 years). The subjects were informed about the study procedure and informed consent was received. Criteria for including a patient were: (i) presence of a single maxillary central incisor affected by an uncomplicated crown fracture, complicated crown fracture, or a root fracture, and (ii) absence

Table 1. Incidence of diagnostic outcomes ($n = 72$)

Diagnostic outcome groups	Incidence (%)	PBF value (PU)
Absence of loss of sensitivity, periapical radiolucency, and grey discoloration (type I)	42 (58.3)	13.2 ± 2.7*
Presence of loss of sensitivity (type II)	16 (22.2)	9.8 ± 3.2*
Presence of loss of sensitivity, periapical radiolucency, and/or grey discoloration (type III)	14 (19.4)	4.3 ± 1.7

PBF, pulpal blood flow; PU, perfusion units; *n*, number of teeth.
*$P = 0.000$. Significant outcome group-related difference.

Table 2. Prevalence of PBF levels: PBF levels by diagnostic groups

	Outcome group ($n = 72$)				
PBF levels (PU)	Presence of loss of sensitivity, periapical radiolucency, and grey discoloration*** (%) ($n = 6$)	Presence of loss of sensitivity and periapical radiolucency*** (%) ($n = 8$)	Presence of loss of sensitivity** (%) ($n = 16$)	Absence of loss of sensitivity, periapical radiolucency, and grey discoloration* (%) ($n = 42$)	Control Group (%) ($n = 72$)
>12.0	–	–	5 (31.3)	22 (52.4)	43 (59.7)
>6.0 ≤ 12.0	–	4 (50.0)	7 (43.8)	20 (47.6)	29 (40.3)
≤6.0	6 (100)	4 (50.0)	4 (25.0)	–	–

PBF, pulpal blood flow; PU, perfusion units; *n*, number of teeth.
*Type I outcome; **type II outcome; ***type III outcome; $\chi^2 = 91.36$; $P = 0.000$; $df = 8$.
Significant association between diagnostic groups and PBF levels.

Table 3. Risk and relative odds of outcomes as a function of PBF measurements ($n = 72$)

	Log odds				
PBF levels (PU)	Estimate	Standard error	Odds ratio	95% CI	*P*
>6.0 ≤ 12.0	0.99	0.62	2.69	–0.22–2.21	0.107
≤6.0	4.67	0.90	106.70	2.89–6.43	0.000

PBF, pulpal blood flow; PU, perfusion units; *n*, number of teeth; CI, confidence interval.

of concomitant dento-alveolar injuries. Each of the subjects was treated with a 0.16 × 0.50 mm wire (Standard Edgewise Wire; Leibinger, Mülheim, Germany). Where a maxillary incisor was missing, the injured central maxillary incisor bore a crown, was root-filled, or had a large filling, LDF data were not collected.

Splint application

The splints were bonded to the labial aspect of all maxillary incisors. The wire was cut to the desired length and then adapted to the curvature of the maxillary incisors using pliers. The splints were secured with identical light-curing composite. After placing cotton rolls in the vestibule, the maxillary incisors were dried with air. Etching of the enamel surface was performed with 35% phosphoric acid gel for 30 s (Totaletch®; Ivoclar Vivadent, Ellwangen, Germany). Subsequently, the gel was rinsed off with water from the dental unit and the etched surfaces were dried again. A thin layer of bonding agent (Heliobond®; Ivoclar Vivadent, Ellwangen, Germany) was applied using a microbrush. The bonding agent was left for 20 s prior to polymerization with a light source for another 40 s.

Apparatus

PBF measurements were performed with an LDF (Periflux PF 4001 Masters; Perimed, Järfälla, Sweden). Light with a wavelength of 632.8 nm was produced by a 1 mW He–Ne laser within the flowmeter and transmitted along a flexible fiber-optic conductor inside a specially designed round dental probe with a diameter of 2 mm (PF 416; Perimed) (19, 20). A fraction of the backscattered light from the tooth was returned to the flowmeter along a pair of afferent optical fibers within the probe. The optical-fiber diameter was 125 μm and the fiber-to-fiber distance was 500 μm. The flowmeter then processed the amount of Doppler-shifted light that was returned and produced an output signal. The measured voltage is linearly related to the flux of red blood cells (number of cells multiplied by their average velocity) encountered within the tooth and represents a relative measure of PBF.

The flowmeter was calibrated prior to each data collection session. The narrow band was adjusted to read zero voltage when the probe was placed against a motionless object, while a commercially available motility standard (Perimed) was used to calibrate the flowmeter on the wide band to a specific value of 250 perfusion units (PU). The artifact filter was activated, and the PBF data were collected on a wide band setting. Voltage output values were sent from the RS-232 port of the flowmeter, at a rate of 32 signals per second, to an Apple Macintosh Plus computer for storage and subsequent analysis.

Procedure

Measurements were recorded on the labial site of each experimental tooth at a location about 5 mm from the gingival margin. For each subject, PU were taken 96 weeks after splint removal. In order to ensure

Table 4. Prevalence of PBF levels: PBF levels by outcome groups

PBF levels (PU)	Ootcome group											
	Control group (n = 14)	Presence of loss of sensitivity, periapical radiolucency, and/or grey discoloration*** (%) (n = 14)	χ^2	P	Control group (%) (n = 16)	Presence of loss of sensitivity** (%) (n = 16)	χ^2	P	Control group (%) (n = 42)	Absence of loss of sensitivity, periapical radiolucency, and grey discoloration* (%) (n = 42)	χ^2	P
>12.0	6 (42.9)	–			11 (68.8)	5 (31.3)			26 (61.9)	22 (52.4)		
>6.0 ≤ 12.0	8 (57.1)	4 (28.6)			5 (31.3)	7 (43.8)			16 (38.1)	20 (47.6)		
≤6.0	–	10 (71.4)	17.33	0.000	–	4 (25.0)	6.58	0.037	–	–	0.78	0.378

PBF, pulpal blood flow; PU, perfusion units; n, number of teeth.
*Type I outcome; **type II outcome; ***type III outcome; χ^2, chi-square for comparison of incisors of control group vs incisors with a specific outcome.

accurate and reproducible spatial positioning of the probe at each session, custom-made clear plastic splints (Bioplast; Schen-Dental, Iserlohn, Germany) were prepared, covering the 74 maxillary teeth and providing appropriately placed holes with a diameter similar to that of the flowmeter probe. After having the patient rest in a supine position in the dental chair for approximately 10 min, blood-flow data were collected for 3 min at each measurement session. The temperature of the room was constant. Attempts were made to minimize bias as a result of the movement of the subjects or probe. Pulse rate and blood pressure were also recorded.

At the end of the follow-up (96 weeks after splint removal), the occurrence of adverse outcomes was assessed both clinically and radiographically. The clinical diagnostic procedures included sensitivity testing with carbon dioxide ice, and evaluation of crowns for changes in colour (5). The radiographic examination of the anterior region consisted of one occlusal film and three periapical exposures, where the central beam was directed between the lateral and central incisors and between the central incisors (5). The teeth were assigned a diagnostic outcome group according to the clinical and radiographical findings. Outcomes were classified as type I (absence of sensitivity, periapical radiolucency, and grey discoloration of crown), type II (loss of sensitivity), or type III (loss of sensitivity, periapical radiolucency, and/or grey discoloration of crown) diagnosis. At each session, when an injured permanent maxillary incisor was recorded, a contralateral homologous tooth was used as a control.

Data analysis

The mean PU for each recording site was calculated during each session by averaging all the individual PU collected for 180 s. Individual PU that registered as movement artifacts were excluded from this average.

Univariate analysis of variance was used to test for outcome group-related differences in PBF values. A Bonferroni correction of the alpha-level for outcome group-related data analysis was performed. Chi-square analysis was performed to analyze the relationship between diagnostic groups and PBF levels of '≤6.0 PU', '>6.0 ≤ 12.0 PU', and '>12.0 PU' (mean and SD cut-off points). An ordinal regression analysis was used for the simultaneous assessment of each potential variable of PBF level ('≤6.0 PU', '>6.0 ≤ 12.0 PU', '>12.0 PU'). Odds ratios were used to describe the proportionate risk that an individual with a PBF level may belong to the more severe outcome group.

Chi-square analysis was used to analyze the relationship between the non-injured control group and the specific outcome groups of types I, II, and III, and PBF levels of '≤6.0 PU', '>6.0 ≤ 12.0 PU', and '>12.0 PU'. A logistic regression analysis was used to compute the odds ratios for the outcome features for incisor non-injury controls vs two outcome groups: types II and III. Odds ratios were used to describe the proportionate risk that an individual with a certain outcome feature may belong to the PBF level group of ≤6.0 PU.

Table 5. Summary of logistic regression analysis for diagnostic outcomes predicting a PBF level outcome of ≤6 PU

PBF levels (PU)	Log odds		Odds ratio	95% CI	*P*
	Estimate	Standard error			
Presence of loss of sensitivity (type II)	1.61	1.18	4.99	0.49–50.79	0.174
Presence of loss of sensitivity, periapical radiolucency, and/or grey discoloration (type III)	3.48	1.19	32.49	3.13–337.72	0.004

PBF, pulpal blood flow; PU, perfusion units; *n*, number of teeth; CI, confidence interval.

A significant odds ratio was defined as an upper and lower 95% confidence limit not containing the value of zero. For the odds ratio to be clinically relevant or even clinically noticeable, it was assumed that it would need to be larger than 2.5. Statistical significance was set at $P < 0.05$. For all statistical analysis the SPSS 10.0.7 software program (SPSS Inc., Chicago, IL, USA) was used.

Results

At 96 weeks follow-up, 58% of the incisors were diagnosed with a type I outcome, while a type II and III outcome occurred in 22% and 19%, respectively. For the PBF measurements the main effect of the variable 'outcome group' ($P = 0.000$) was significant, i.e. the outcome groups differed significantly. Analysis of outcome group-related differences indicated that PBF measurements of type I outcomes were significantly higher than those of the other outcomes ($P = 0.000$), whereas PBF measurements of type II were significantly higher than those of the type III outcomes ($P = 0.000$) (Table 1).

Using chi-square analysis for pair-wise comparison, the data demonstrated a significant relationship between PBF measurements and diagnostic groups ($P = 0.000$) (Table 2). PBF measurements which were significantly associated with more severe outcome were PBF levels of ≤6 PU (106.7 odds ratio) ($P = 0.000$) (Table 3).

Comparing the outcome group-related data with those of the non-injury control group, the results of chi-square analysis showed a significant relationship between the outcome groups and the PBF levels for the type II ($P = 0.037$) and type III outcome groups ($P = 0.000$) (Table 4). Significant increase in risk of a PBF level of ≤6 PU occurred with a type III outcome (32.49 odds ratio) ($P = 0.004$) (Table 5).

Discussion

With the most prominent finding of significantly lower overall PBF values associated with type II and III outcomes as compared with those of type I outcomes, the results support the concept of a direct link between dental fracture types and the occurrence of functional and/or structural pulpal tissue changes (21–23). In several studies pulp necrosis was described as a common complication after crown and root fractures, the incidence rates are described with 20–44% for root fractures and 100% for crown-root fractures (24–27).

Root fracture represents a very complex wound, involving disruption of the periodontal ligament fibers, cementum, dentin, and the neurovascular supply to the pulp (6, 23). This type of injury usually involves the maxillary incisors (28) and occurs with a higher frequency in the permanent than the primary dentition (2, 4). Complications include pulp necrosis, pulp obliteration, internal or external root absorption, and loss of marginal bone support pulp (6, 23, 29). Such complications may require extraction or root canal treatment (23, 29–32). The risk of pulpal necrosis increases with the extent of injury to the pulp and periodontal ligament, and in the teeth with complete root formation (33). With regard to the high incidence of pulp necrosis (24–27), prophylactic extirpation of the pulp has been recommended to prevent other complications arising from the pulp necrosis (23, 30). LDF may be valuable in monitoring traumatized incisors during the immediate post-trauma phase. The best outcome for the post-traumatized incisor is for it to revascularize and continue normal root development. LDF may be used in helping to establish that revascularization was occurring long before this data could be derived from traditional sensitivity tests. Identification of revascularization with conventional sensitivity testing may lead to infection in the post-trauma observation period.

The present study provides a perspective to the contribution of the variables of PBF characteristics to the outcomes of dental trauma splinting. In the specific subgroup of 'permanent maxillary incisor affected by a fracture injury', the parameters of 'PBF level of ≤6.0 PU' contributed a significant amount to the change in prognosis of dental trauma splinting outcomes. However, although a clear definition of the outcome group was evident for these parameters, they may not be considered the unique and dominant factors in the definition of dental trauma splinting outcome groups. However, the contribution of these variables was not zero, and the elevation in the odds ratios indicate that they probably make some contribution biologically. Further investigations are necessary to answer the question which additional morphological and functional features may have to be defined as 'prognostic for specific outcomes'.

The current study may suffer from the inadequacy of the control group. The control group contains too much 'noise' by including incisors from individuals with signs and symptoms of dental trauma. In tests for differences between populations, the maxim that the ideal control population should be the least symptomatic available and the ideal study sample the most diseased needs to be followed. Further multiple factor studies that incorporate additional morphological variables and a wellness 'gold standard' without signs, symptoms, or history of dental trauma should be encouraged.

Odds ratios were used to describe the proportionate risk that an individual with a PBF level may belong to specific outcome groups. An estimation of the absolute risk for acquiring a specific outcome in the population rather than the relative risk would require substitution of the real prevalence of the disorder into the regression equations. In the current study, it must be emphasized that the odds ratios apply only to the specific patient population selected.

These findings raise the question of whether the use of clinical and radiological findings may need to be supplemented by PBF measurements to distinguish among subtypes of dental fracture injuries. From a methodological point of view, etiology, prognostic statements, and implications for treatment are considered to be the main indicators for the utility of diagnostic classifications (34). Further research may be warranted to assess the diagnostic validity of PBF characteristics by determining how well these diagnoses may show decisive differences in the areas of treatment and/or prognosis.

LDF may be used to assess the degree and duration of dental trauma-related ischemic episodes, thereby identifying patients at risk for adverse sequelae such as avascular necrosis and tissue loss. Although root fractures are uncommon as compared with other types of traumatic injury in the permanent dentition, constant attention must be given to the pulp tissue and periodontal structures, because of the high frequency of complications following this type of injury. In addition, the complication may be unpredictable and the treatment becomes complex and has to be adaptable to any complications that may arise. The outcomes of repositioning may vary and may not be predicted from the appearance or extent of injury sustained clinically. Further studies are warranted to assess the validity of post-traumatic LDF/PBF measurements by comparing it with histological tooth pulp changes, and by determining how well diagnoses of PBF may predict course and response to treatments in clinical trials.

Conclusion

PBF measurements were related to the severity of adverse outcomes. Diagnoses of treatment outcomes predicted the presence of specific PBF levels.

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