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Adverse outcomes of dental trauma splinting as related to displacement injury and pulpal blood flow level

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Abstract – Splinting of traumatically displaced permanent teeth has been described as an effective modality in the treatment of patients with dental injuries. The purpose of this study was to (i) investigate whether dental injury diagnosis may predict adverse outcomes occurring 96 weeks after splint removal, and (ii) evaluate whether the severity of adverse outcome is related to laser Doppler flowmetry (LDF) measurements of pulpal blood flow (PBF). In 206 trauma patients, 273 permanent maxillary incisors treated by repositioning and splinting, and the respective contralateral homologous control teeth were investigated clinically and radiographically, and by LDF to assess local PBF values. Dental displacement injuries were classified as grade I (subluxation), grade II (lateral or extrusive luxation) and grade III (avulsion or intrusive luxation). Outcomes were classified as 'absence of loss of sensitivity, periapical radiolucency, and/or grey discolouration of crown', type I (loss of sensitivity), type II (loss of sensitivity and periapical radiolucency or grey discoloration of crown) and type III (loss of sensitivity, periapical radiolucency and grey discoloration of crown). An adverse outcome was defined as the presence of 'periapical radiolucency and/or grey discoloration'. A multiple logistic regression analysis was used to compute the odds ratio (OR) for dental displacement injury for adverse outcome ($n = 69$) vs non-adverse outcome ($n = 168$). An ordinal stepwise regresssion was completed to assess the degree of association between PBF measurements and outcome groups. Significant increase in risk of an adverse outcome occurred with a grade II dental displacement injury (OR 14.3) ($P = 0.000$) and a grade III dental displacement injury (OR 19.9) ($P = 0.000$). PBF measurements that were significantly associated with more severe outcome were PBF levels of ≤3 perfusion units (PU) (OR 399.4) ($P = 0.000$), those of >3 PU and ≤6 PU (OR 100.5) ($P = 0.000$), and those of >6 PU and ≤9PU (OR 6.2) ($P = 0.000$). Diagnoses of displaced teeth predicted dental injury patients who went on to show adverse treatment outcomes of splinting. PBF measurements were related to the severity of adverse outcome.

Traumatically displaced permanent teeth require a splint for stabilization following repositioning or replantation (1, 2). Treatment outcome of dislocated 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. The course of healing of the severed periodontal ligament and the neurovascular supply to the pulp determine the treatment outcome of the injured teeth (3).

Use of back-scattered light (laser Doppler flowmetry, LDF) enables a non-invasive semiquantitative recording of pulpal blood flow (PBF) (4). LDF has been described as a more sensitive technique for evaluating tooth vitality compared with conventional methods such as electrical and thermal pulp testing (5–9). The major advantages of LDF are that it is non-invasive, and that measurements may be made continuously. The major disadvantages of LDF are that the measurements are sensitive to artefacts such as movement or pressure, and that the equipment necessary for this procedure is bulky and costly.

Several authors reported the use of flowmetric values to demonstrate the reestablishment of vitality in traumatized teeth(5, 6, 8–11). In instances of dental trauma LDF may be useful in the detection of transient ischaemic episodes and the identification of teeth at risk for adverse outcomes (12–14). The purpose of this study was to (i) investigate whether dental injury diagnosis may predict adverse outcomes occurring 96 weeks after splint removal, and (ii) evaluate whether the severity of adverse outcome is related to LDF measurements of PBF.

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Materials and methods

Subjects

The study group of 206 consecutive dental trauma patients included 98 women and 108 men, with a mean age of 27.5 years (range 5–56 years). Patients were referred from medical practitioners and dentists in the community to the Department of Oral and Maxillofacial Surgery at the University of Innsbruck. This clinic is the primary referral centre for dental injuries at the institution because both conservative and surgical treatments are offered. Each subject was treated by tooth repositioning and splinting with a 0.16 mm × 0.50 mm wire (Standard Edgewise Wire; Leibinger, Mülheim, Germany). The subjects were informed about the study procedure and informed consent was obtained.

Criteria for including a patient were (i) presence of a permanent maxillary incisor affected by a subluxation, intrusion, lateral luxation, extrusion, or avulsion injury, (ii) absence of concomitant dento-alveolar injuries, and (iii) trauma < 2 h previously. Dental displacement injuries were classified as grade I (subluxation), grade II (lateral or extrusive luxation) and grade III (avulsion or intrusive luxation). 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 37% 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 was (Heliobond®; Ivoclar Vivadent) 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

Pulpal blood flow measurements were performed with a laser Doppler flowmeter (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 fibreoptic conductor inside a specially designed round dental probe with a diameter of 2 mm (PF 416; Perimed) (15). A fraction of the backscattered light from the tooth was returned to the flowmeter along a pair of afferent optical fibres within the probe. The optical fibre diameter was 125 μm, and fibre-to-fibre 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), i.e. the laser Doppler flowmeter was set up so that the Brownian motion of the latex particles in the Perimed motility standard gave a blood flow signal of 2.5 V or 250 PU with the wide bandwith settings (12 kHz upper limit). The artefact 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 about 5 mm from the gingival margin. For each subject, PUs were taken 96 weeks after splint removal. To ensure 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 237 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 caused by 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 carbone dioxide ice, and evaluation of crowns for changes in colour (16). 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 (13). The teeth were assigned a diagnostic outcome group according to the clinical and radiographical findings. Outcomes were classified as 'absence of loss of sensitivity, periapical radiolucency, and/or grey discoloration of crown', type I (loss of sensitivity), type II (loss of sensitivity, and periapical radiolucency or grey discoloration of crown) and type III (loss of sensitivity, periapical radiolucency and grey discoloration of crown) (14). An adverse outcome was defined as the presence of 'periapical radiolucency and/or grey discoloration'. The non-adverse outcome was defined according to the finding of an absence of an adverse outcome. At each session, when an injured permanent maxillary incisor was recorded, a contralateral homologous tooth was used as a control.

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Table 1. Dental displacement injury by diagnostic outcomes (n = 237)

	Adverse outcome (n = 69)			Non-adverse outcome (n = 168)	
Dental displacement injury	Presence of loss of sensitivity and periapical radiolucency[b] (%) (n = 20)	Presence of loss of sensitivity and grey discoloration[b] (%) (n = 12)	Presence of loss of sensitivity, periapical radiolucency and grey discoloration[c] (%) (n = 37)	Presence of loss of sensitivity[a] (%) (n = 72)	Absence of loss of sensitivity, periapical radiolucency and grey discoloration (%) (n = 96)
Subluxation (grade I) (n = 74)	–	–	3 (8.1)	8 (11.1)	63 (65.6)
Lateral and extrusive luxation (grade II) (n = 106)	12 (60.0)	7 (58.3)	21 (56.8)	45 (62.5)	21 (21.9)
Avulsion and intrusive luxation (grade III) (n = 57)	8 (40.0)	5 (41.7)	13 (35.1)	19 (26.4)	12 (12.5)

Adverse outcome, presence of periapical radiolucency and/or grey discoloration; non-adverse outcome, absence of periapical radiolucency and grey discoloration; *n*, number of teeth.
[a]Type I outcome group.
[b]Type II outcome group.
[c]Type III outcome group

Data analysis

Chi-square analysis was performed to test for the relationship between treatment outcome and dental injury type. A multiple logistic regression analysis was used for the simultaneous assessment of each potential variable of dental displacement injury (grades I–III). Odds ratios (OR) were used to describe the proportionate risk that an individual with a certain dental displacement injury may belong to the adverse treatment outcome group. A significant OR was defined as an upper and lower 95% confidence limit not containing the value of zero. For the OR be clinically relevant or even clinically noticeable, it was assumed that it would need to be larger than 2.5. The outcome was always adverse treatment outcome vs non-adverse treatment outcome.

The mean PU for each recording site was calculated during each session by averaging all the individual PUs collected for 180 s. Individual PUs that registered as movement artefacts 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 analyse the relationship between PBF levels and outcome groups. An ordinal regression analysis was used for the simultaneous assessment of each potential variable of PBF level ($\leq$3.0 PU; $>$3.0 and $\leq$6.0 PU; $>$6.0 PU and $\leq$9.0 PU; $>$9.0 PU and $\leq$12.0 PU). OR were used to describe the proportionate risk that an individual with a PBF level may belong to the more severe outcome group. A significant OR was defined as an upper and lower 95% confidence limit not containing the value of zero.

Statistical significance was set at $P < .05$. For all statistical analysis the SPSS 10.0.7 software program (SPSS Inc., Chicago, IL, USA) was used.

Results

At the 96-week follow-up, 69 (29%) incisors demonstrated a diagnosis of an adverse outcome, while only 168 (71%) showed no clinical or radiographical findings of an adverse outcome (Table 1).

The distribution of dental displacement injury of the incisors is presented in Table 1. For the outcome criteria of 'presence of periapical radiolucency and/or grey discoloration', there was a significant association between the treatment outcome groups and the variables of dental displacement injury (P = 0.000) (Table 2).

Significant increase in risk of an adverse outcome occurred with a grade II dental displacement injury (OR 14.3) (P = 0.000), and a grade III dental displacement injury (OR 19.9) (P = 0.000) (Table 3).

At the 96-week follow-up, 59% of the incisors were diagnosed with a type I, type II and type III outcome, while 41% had an 'absence of loss of sensitivity, periapical radiolucency, and/or grey discoloration of crown'. The most common diagnosis was loss of sensitivity (30%). A type II and III outcome occurred in 14% and 16% respectively (Table 4).

For the PBF measurements the main effect of the variable 'outcome group' was significant (P = 0.000). Analysis of outcome group-related differences indicated that PBF measurements of 'absence of loss of sensitivity, periapical radiolucency, and/or grey discolouration of

Table 2. Comparison of dental displacement injuries between adverse and non-adverse treatment outcomes (n = 237)

	Teeth		
Dental displacement injury	Adverse outcome (%) (n = 69)	Non-adverse outcome (%) (n = 168)	Sum (%) (n = 237)
Subluxation (grade I)	3 (4.3)	71 (42.3)	74 (31.2)
Lateral and extrusive luxation (grade II)	40 (58.0)	66 (39.3)	106 (44.7)
Avulsion and intrusive luxation (grade III)	26 (37.7)	31 (18.5)	57 (24.1)

Adverse outcome, presence of periapical radiolucency and/or grey discoloration; non-adverse outcome, absence of periapical radiolucency and grey discoloration; *n*, number of teeth. χ^2 = 33.856; P = 0.000; d.f. = 2. Significant association between treatment outcomes and dental displacement injuries.

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Table 3. Relative odds of adverse treatment outcomes as a function of dental displacement injury (n = 237)

Diagnostic factor	Log odds: Estimate	Log odds: Standard error	Odds ratio	95% CI	*P*
Dental displacement injury					
Lateral and extrusive luxation (grade II)	2.66	0.62	14.34	4.23–48.59	0.000
Avulsion and intrusive luxation (grade III)	2.99	0.65	19.85	5.59–70.50	0.000

n, number of teeth.

Table 4. Incidence of outcome groups (n = 237)

Outcome groups	Incidence (%)	PBF value (PU)
Absence of loss of sensitivity, periapical radiolucency and grey discoloration	96 (40.5)	11.5 ± 2.9*
Presence of loss of sensitivity, periapical radiolucency or grey discoloration	141 (59.5)	5.6 ± 4.1
Presence of loss of sensitivity (type I)	72 (30.4)	8.3 ± 4.0*
Presence of loss of sensitivity, and periapical radiolucency or grey discoloration (type II)	32 (13.5)	3.6 ± 2.4
Presence of loss of sensitivity, periapical radiolucency and grey discoloration (type III)	37 (15.6)	2.3 ± 1.5

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

crown' and type I outcomes were significantly higher than those of the other outcomes (P = 0.000), while PBF measurements of type II and type III outcomes did not differ (P = 0.536) (Table 4).

Using chi-square analysis for pair-wise comparison, the data demonstrated a significant relationship between PBF measurements and outcome groups (P = 0.000) (Table 5). PBF measurements that were significantly associated with more severe outcome were PBF levels of ≤3 PU (OR 399.4) (P = 0.000), those of >3 PU and ≤6 PU (OR 100.5) (P = 0.000), and those of >6 PU and ≤9 PU (OR 6.2) (P = 0.000) (Table 6).

Table 6. Risk and relative odds of diagnostic outcomes as a function of PBF measurements

PBF levels (PU)	Log odds: Estimate	Log odds: Standard error	Odds ratio	95% CI	*P*
>9.0 ≤ 12.0	0.45	0.40	1.57	−0.35–1.24	0.269
>6.0 ≤ 9.0	1.82	0.38	6.17	1.08–2.57	0.000
>3.0 ≤ 6.0	4.61	0.46	100.48	3.72–5.50	0.000
<3.0	5.99	0.50	399.41	5.02–6.96	0.000

PBF, pulpal blood flow; PU, perfusion unit.

Discussion

Dental injuries that involve displacement of the tooth in or out of the alveolar socket may represent a very complex wound, involving disruption of the marginal gingival seal, alveolar bone, periodontal ligament fibres, cementum and the neurovascular supply to the pulp (16). Complications include ankylosis, pulp necrosis, pulp obliteration, external root resorption and loss of marginal bone support (16–19). In several studies pulp necrosis was described as the most common complication after luxation injuries (19–21). Prophylactic extirpation of the pulp has been recommended to prevent other complications arising from the pulp necrosis (21, 22). Treatment outcome of displaced maxillary incisors may depend on several factors such as injury type, degree of dislocation, concomitant dento-alveolar injuries, stage of root formation, time period between trauma and treatment, and type of dental trauma splint. However, the contribution of these variables is unknown.

The present study provides a perspective to the contribution of the variables of dental displacement injury to the outcomes of dental trauma splinting. In the specific subgroup of 'permanent maxillary incisor affected by a subluxation, luxation, or avulsion type injury' the parameters of 'grade II dental displacement injury' and 'grade III dental displacement injury' contributed significantly to the change in prognosis of dental trauma splinting outcomes. However, although a clear definition of the outcome groups 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

Table 5. Prevalence of PBF levels by diagnostic outcome groups

PBF levels (PU)	Presence of loss of sensitivity, periapical radiolucency and grey discoloration[c] (%) (n = 37)	Presence of loss of sensitivity, and periapical radiolucency or grey discoloration[b] (%) (n = 32)	Presence of loss of sensitivity[a] (%) (n = 72)	Absence of loss of sensitivity, periapical radiolucency and grey discoloration (%) (n = 96)	Control Group (%) (n = 237)
>12.0	–	–	12 (16.7)	31 (32.3)	114 (48.1)
>9.0 ≤ 12.0	–	–	16 (22.2)	41 (42.7)	82 (34.6)
>6.0 ≤ 9.0	–	5 (15.6)	23 (31.9)	23 (24.0)	32 (13.5)
>3.0 ≤ 6.0	12 (32.4)	14 (43.8)	11 (15.3)	1 (1.0)	9 (3.8)
≤3.0	25 (67.6)	13 (40.6)	10 (13.9)	–	–

PBF, pulpal blood flow; PU, perfusion unit; *n*, number of teeth. χ^2 = 353.161; P = 0.000; d.f. = 16. Significant association between adverse outcomes and PBF levels.
[a]Type I outcome group
[b]Type II outcome group
[c]Type III outcome group

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these variables was not zero, and the elevation in the OR indicates that they are probably making some contribution biologically. Further investigations are necessary to determine 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 studies that incorporate a wellness 'gold standard' without signs, symptoms, or history of dental trauma should be encouraged.

The present study demonstrated that the LDF technique was able to detect outcome-related differences in PBF measurements at the 96-week follow-up. PBF measurements were found to be significantly associated with the occurrence of specific outcomes. PBF values approached and dropped below 4 PU for type II and III outcomes, whereas in outcomes of 'absence of loss of sensitivity, periapical radiolucency, and/or grey discoloration of crown' the PBF value remained above 11 PU. This is of clinical significance and may be implicated as a possible cause in the development of subsequent degenerative and atrophic pulpal changes. Therefore, LDF may be used to monitor incisors during the post-trauma phase. It may help to identify 'ischaemic episodes' long before this may be derived from traditional clinical tests.

The present study provides a perspective to the contribution of the variables of PBF characteristics to the outcomes of dental trauma splinting. The parameters 'PBF level of ≤3.0 PU', 'PBF level of >3 PU and ≤6 PU', and 'PBF level of >6 PU and ≤9 PU' contributed significantly to the change in outcome of dental trauma splinting outcomes. OR were used to describe the proportionate risk that an individual with a PBF level may belong to the more severe outcome group. 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 OR apply only to the specific patient population selected.

The findings raise the question of whether the use of clinical and radiological findings need to be supplemented by PBF measurements to distinguish among subtypes of dental injuries. From a methodological point of view, aetiology, prognostic statements and implications for treatment are considered to be the main indicators for the utility of diagnostic classifications (23). Further research is 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.

Conclusion

Diagnoses of displaced teeth predicted dental injury patients who went on to show adverse treatment outcomes of splinting. PBF measurements were related to the severity of adverse outcome.

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