Laser Doppler flow measurements of pulpal blood flow and severity of dental injury

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Abstract

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Aim To evaluate laser Doppler flowmetry (LDF) measurements of pulpal blood flow (PBF) and severity of dental injury.

Methodology The relationship between adverse outcomes and PBF measurements was analysed in 94 permanent maxillary incisors of 71 consecutive dental trauma patients. The diagnostic adverse outcome group was comprised of 72 incisors in 52 patients with a type I (loss of sensitivity), type II (loss of sensitivity and periapical radiolucency), or type III (loss of sensitivity, periapical radiolucency and grey discoloration of crown) diagnosis. The nonadverse outcome group consisted of 22 incisors in 19 patients with 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. An ordinal stepwise regression was completed to assess the degree of association between PBF measurements and adverse outcomes

Results Using chi-square analysis for pairwise comparison, a significant relationship between PBF measurements and types of adverse outcomes ($\chi^2 = 119.635$, d.f. $= 12$, $P = 0.000$) was observed. PBF measurements that were significantly associated with more severe outcome were PBF levels of ≤3 perfusion units (PU) (119.1 odds ratio) ($P = 0.000$), and those of >3 PU and ≤6 PU (12.7 odds ratio) ($P = 0.000$).

Conclusions PBF measurements were related to the severity of adverse outcomes. Further studies are required to evaluate whether PBF measurements can predict dental injuries that progress to adverse treatment outcomes.

Keywords: dental splint, dental trauma, laser Doppler flowmetry, luxation injuries, maxillary incisors, pulpal blood flow.

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Introduction

Use of electro-optical techniques such as transmitted-light photoplethysmography, transmitted laser light, and back-scattered light (laser Doppler flowmetry, LDF) enable noninvasive semi-quantitative recording of pulpal blood flow (PBF) (Ingolfson *et al.* 1994, Sasano *et al.* 1997, Miwa *et al.* 2002). PBF measurement using LDF has been described as a more sensitive technique for evaluating tooth vitality compared with conventional methods such as electrical and thermal pulp testing (Gazelius *et al.* 1988, Olgart *et al.* 1988, Evans *et al.* 1999, Lee *et al.* 2001, Roeykens *et al.* 2002). The technique uses a helium-neon laser light beam that is directed into the tooth. Light that contacts a moving object is Doppler-shifted, and a portion of that light is backscattered out of the tooth and returned to the photodetector, and a signal is produced. As red blood cells represent the vast majority of moving objects within the tooth, measurement of the Doppler-shifted backscattered light serves as an index of PBF. The major advantages of LDF are that it is noninvasive, and that measurements may be made continuously. The major disadvantages of LDF are that the measurements

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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 (Gazelius *et al.* 1988, Olgart *et al.* 1988, Ebihara *et al.* 1996, Mesaros & Trope 1997, Lee *et al.* 2001, Roeykens *et al.* 2002). 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 such as avascular necrosis and tissue loss. The purpose of this study was to evaluate whether the severity of adverse outcomes of dental injuries were related to LDF measurements of PBF.

Materials and methods

Subjects

The study group of 71 consecutive dental trauma patients included 23 females and 48 males, with a mean age of 25.5 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 of the subjects 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 given.

Criteria for including a patient were: (i) presence of a permanent maxillary incisor affected by a luxation type injury, (ii) absence of concomitant dento-alveolar injuries, and (iii) trauma <2 h previously. 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

PBF 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 helium-neon laser within the flowmeter and transmitted along a flexible fibre-optic conductor inside a specially designed round dental probe with a diameter of 2 mm (PF 416; Perimed) (Ramsay *et al.* 1991). 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, whilst 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 at a location about 5 mm from the gingival margin. For each subject, PU were taken

36 weeks after splint removal. In order 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 94 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 due to movement of the subjects or probe. Pulse rate and blood pressure were also recorded.

At the end of the follow-up (36 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 (Andreasen & Andreasen 1994). 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 (Andreasen & Andreasen 1994). The teeth were assigned a diagnostic outcome group according to the clinical and radiographical findings. Adverse outcomes were classified as type I (loss of sensitivity), type II (loss of sensitivity and periapical radiolucency), and type III (loss of sensitivity, periapical radiolucency, and grey discoloration of crown) (Table 1). The nonadverse 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.

Data analysis

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 α-level for outcome group-related data analysis was performed. Chi-square analysis was carried out to analyse the relationship between treatment outcome and PBF levels. 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) (mean and standard deviation cut-off points). Odds ratios were used to describe the proportionate risk that an individual with a PBF level may belong to the more severe outcome group. A significant odds ratio was defined as an upper and lower 95% confidence limit not containing the value of zero.

Table 1 Adverse outcomes associated with dental injuries (number of teeth, $n = 94$)

Diagnostic outcome	Diagnostic criteria
Type I	Loss of sensitivity
Type II	Loss of sensitivity and presence of periapical radiolucency
Type III	Loss of sensitivity, presence of periapical radiolucency, and presence of discoloration of crown

Results

At the 36 weeks follow-up, 77% of the incisors were diagnosed with an adverse outcome, whilst only 23% had no clinical or radiographical finding of an adverse outcome. The most common diagnosis was loss of sensitivity (37%). A type II and III outcome occurred in 20 and 19%, respectively (Table 2).

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 nonadverse and type I outcomes were significantly higher than those of the other outcomes ($P = 0.000$), whilst PBF measurements of type II and type III outcomes ($P = 0.110$) did not differ (Table 2).

Using chi-square analysis for pairwise comparison, the data demonstrated a significant relationship between PBF measurements and types of adverse outcomes ($P = 0.000$) (Table 3). PBF measurements which were significantly associated with more severe outcome were PBF levels of $\leq$3 PU (119.1 odds ratio)

Table 2 Incidence of diagnostic outcome groups (number of teeth, $n = 94$)

Diagnostic outcome	Incidence (%)	PBF value (PU)
Absence of adverse outcome	22 (23.4)	9.6 ± 2.1*
Presence of adverse outcome	72 (76.6)	4.8 ± 4.2
Type I	35 (37.2)	7.6 ± 4.1*
Type II	19 (20.2)	2.4 ± 2.3
Type III	18 (19.2)	1.8 ± 1.7

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

Table 3 Prevalence of PBF levels: PBF levels by diagnostic groups

PBF levels (PU)	Loss of sensitivity, periapical radiolucency and grey discoloration (%) ($n = 18$)	Loss of sensitivity and periapical radiolucency (%) ($n = 19$)	Loss of sensitivity (%) ($n = 35$)	Nonadverse outcome (%) ($n = 22$)	Control group (%) ($n = 71$)
>9.0	–	–	11 (31.4)	11 (50.0)	45 (63.4)
>6.0 ≤ 9.0	–	2 (10.5)	9 (25.7)	10 (45.5)	20 (28.2)
>3.0 ≤ 6.0	5 (27.8)	4 (21.1)	11 (31.4)	1 (4.5)	6 (8.5)
≤3.0	13 (72.2)	13 (68.4)	4 (11.4)	–	–

PBF, pulpal blood flow; PU, perfusion units; *n*, number of teeth. $\chi^2 = 119.635$; $P = 0.000$; d.f. = 12. Significant association between adverse outcomes and PBF levels.

Table 4 Risk and relative odds of adverse outcomes as a function of PBF measurements

PBF levels (PU)	Log odds		Odds ratio	95% CI	*P*
	Estimate	Standard error			
>6.0 ≤ 9.0	0.15	0.59	1.16	−1.00–1.31	0.797
>3.0 ≤ 6.0	2.54	0.63	12.68	1.31–3.78	0.000
<3.0	4.78	0.71	119.10	3.38–6.17	0.000

PBF, pulpal-blood flow; PU, perfusion units; *n*, number of teeth.

($P = 0.000$), and those of >3 PU and ≤6 PU (12.7 odds ratio) ($P = 0.000$) (Table 4).

Discussion

Luxation injury may represent a complex wound, involving disruption of the marginal gingival tissues, alveolar bone, periodontal ligament fibre, cementum and the neurovascular supply to the pulp (Andreasen & Andreasen 1994). In several studies pulp necrosis was described as the most common complication after luxation injuries (Andreasen 1970, Andreasen & Petersen 1985, Andreasen & Andreasen 1994). Treatment outcome of luxated maxillary incisors may depend on several factors such as luxation 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 demonstrated that the LDF technique was able to detect outcome-related differences in PBF measurements at the 36-week follow-up. PBF measurements were found to be significantly associated with the occurrence of specific adverse outcomes. PBF values approached and dropped below 3 PU for type I and II outcomes, whereas in nonadverse outcomes the PBF value remained above 9 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. 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.

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 luxation injury' the parameters of 'PBF level of ≤3.0 PU' and 'PBF level of >3 PU and ≤6 PU' contributed a significant amount to the change in prognosis of dental trauma splinting outcomes. However, although a clear definition of the adverse 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 are probably making 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 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 odds ratios apply only to the specific patient population selected.

The findings raise the question of whether the use of clinical and radiological findings may need to be supplemented by PBF measurements to distinguish amongst 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 (Swets 1988). 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.

Conclusion

The results suggest that PBF measurements are related to the severity of adverse outcomes. Further studies are warranted to evaluate whether PBF measurements may predict dental injury patients who went on to show adverse treatment outcomes.

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