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A new method for the non-invasive measurement of pulpal blood flow

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Summary. Laser Doppler flowmetry was used as a new non-invasive method of measuring pulpal blood flow in man. Pulpal perfusion levels were compared between 55 teeth with varying depths of caries, and 183 caries-free teeth in 60 matched patients. With increasing depth of carious lesions, progressively higher pulpal blood flow values were recorded. Caries removal, application of calcium hydroxide paste and temporary dressing restored to normal pulpal blood flow levels in all teeth with superficial dentine caries and in two-thirds of teeth with deep dentine caries. The majority of teeth failing to demonstrate a favourable response within 14 days of treatment became non-vital within 6 months. Direct measurement of pulpal health and treatment response by laser Doppler flowmetry provided an excellent basis for accurate assessment of prognosis and informed treatment planning; this is particularly valuable where a problematic diagnosis requires clarification or where extensive restorative procedures are under consideration.

Introduction

The final condition of the pulp of any tooth is a summation of the effects of caries or trauma, cavity preparation and filling material. These three parameters have been examined in many ways: in animals, for example, by histology, tissue pressure measurements, isotope clearance, radiolabelled microspheres and photoplethysmography. For obvious reasons, investigations on human teeth tend to be rather more restricted, with post-extraction histology providing the majority of information; this has been reviewed by Tönder (1980). Until very recently direct, non-

invasive measurement of pulpal blood flow (PBF) in human teeth has not been possible.

Laser Doppler flowmetry (LDF) was developed to assess blood flow in microvascular systems, e.g. in the retina, gut mesentery, renal cortex and skin (Holloway 1983). This technique utilized a light beam from a Helium-Neon laser at 632.8 nm, which, when scattered by moving red cells, underwent a frequency shift according to the Doppler principle. A fraction of the light back-scattered from the illuminated area was frequency shifted in this way. This light was detected and processed to produce a signal which was a function of the red cell flux (volume of cells illuminated \times mean cell velocity). This can be used as a measure of blood flow, the value being expressed as a percentage of full scale deflection (percentage FSD) at a given gain.

This study was undertaken with the following aims:

- (i) to develop and assess a non-invasive method of measuring PBF in human teeth;
- (ii) to examine differences in PBF between matched patients;
- (iii) to determine whether different types of teeth have characteristic levels of PBF, e.g. whether maxillary central incisors have a greater PBF than mandibular second molars;
- (iv) to monitor the influence of caries depth on PBF, and to observe the effect of caries removal, calcium hydroxide application and temporary restoration on these teeth.

Material and methods

Thirty healthy non-smokers aged 19–34 years, (mean age 26.3 years; 13 male, 17 female) with

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no active carious lesions were selected as matched controls for thirty patients with varying degrees of active caries (aged 19–33 years, mean age 26.1 years; 13 male, 17 female; non-smokers).

In the control group, the PBF of 183 clinically and radiographically healthy teeth was measured once a week for 4 weeks, to assess reproducibility of readings and to investigate intra- and inter-patient PBF characteristics. For each tooth, PBF measurements were taken from the mesial, mid-buccal and distal aspects with the laser probe pointing towards the pulp. Patients were asked to abstain from hot, cold or alcoholic foods or beverages for at least 2 hours before attending.

Fifty-five carious teeth in the 30 patients under investigation were examined clinically and radiographically and allocated to one of the following three groups:

- Group 1: no symptoms, superficial caries affecting enamel (15 teeth).
- Group 2: short stabs of pain elicited by hot and cold stimuli, superficial dentine caries (23 teeth).
- Group 3: spontaneous sharp pain of longer duration, deep dentine caries, no pulpal exposure evident (7 teeth).

All teeth gave a positive response to electrical and thermal vitality tests. In groups 2 and 3, only patients with symptoms were included in the study, in an attempt to restrict the scope of this investigation to active caries.

In all three groups, initial PBF readings were taken at the assessment stage. Caries was then carefully removed using round and fissure tungsten carbide burs in a low-speed handpiece at 15,000 rev/minute under constant irrigation from an attached waterspray. Cutting was intermittent (5–10 seconds) using light pressure. This method reduced pulpal damage from cavity preparation to negligible proportions (Brännström 1960, Plant & Jones 1976). Calcium hydroxide paste (Dycal¹) was applied and the cavities were temporarily sealed with Cavit². Further PBF readings were taken after 3 and 14 days, and, in group 3, also after 2 months.

¹Dycal, L. D. Caulk Co, Milford, Delaware, USA.

²Cavit, Espe GmbH, D-8031 Seefeld, Oberbay, W. Germany.

Blood flow measurements were performed using a commercially available stainless steel fibre optic probe and a laser Doppler flowmeter (Periflux, Pf 2³). The flowmeter's time constant was set at 0.2 seconds, the gain at 10 times and the band width at 4 kHz. Measurements were recorded on a Philips PM 8043 X-Y pen recorder⁴. Blood flow measurements were taken by holding the probe against the tooth until a relatively constant trace was obtained for at least 10 seconds.

Results

The coefficient of variation of flow measurements at individual sites was 8.9 per cent. The standard deviation for all blood flow measurements lay at 7.9 per cent.

Pulpal blood flow values for an individual tooth at any one time varied by an average 4.6 per cent, when comparing readings taken from the mesial, mid-buccal or distal aspect. This difference was not significant ($P > 0.05$) even in molars.

Between individual patients, average PBF of healthy, untreated teeth ranged from 15.8 per cent to 18.4 per cent FSD, with a mean value of 16.9 per cent FSD. This inter-patient variation was not significant.

The mean PBF was calculated for each type of tooth, e.g. all maxillary central incisors. No significant difference was found between individual types of teeth. Similarly, no significant difference was apparent between PBF in maxillary and in mandibular teeth, although maxillary teeth tended to demonstrate slightly higher PBF levels (Fig. 1).

The mean initial PBF in teeth with superficial caries affecting enamel measured 15.4 per cent FSD; in sound teeth the mean PBF lay at 16.9 per cent FSD; these figures did not differ significantly.

Three days after caries removal and dressing there was no significant change in the mean PBF, which measured 16.9 per cent FSD. The same applied to measurements after 14 days, mean 16.1 per cent FSD (Fig. 2).

Superficial dentine caries raised the mean PBF level to 22.0 per cent FSD; this differed

³Perimed KB, Stockholm, Sweden.

⁴Philips Elektrogesellschaft, D-6800 Mannheim 31, W. Germany.

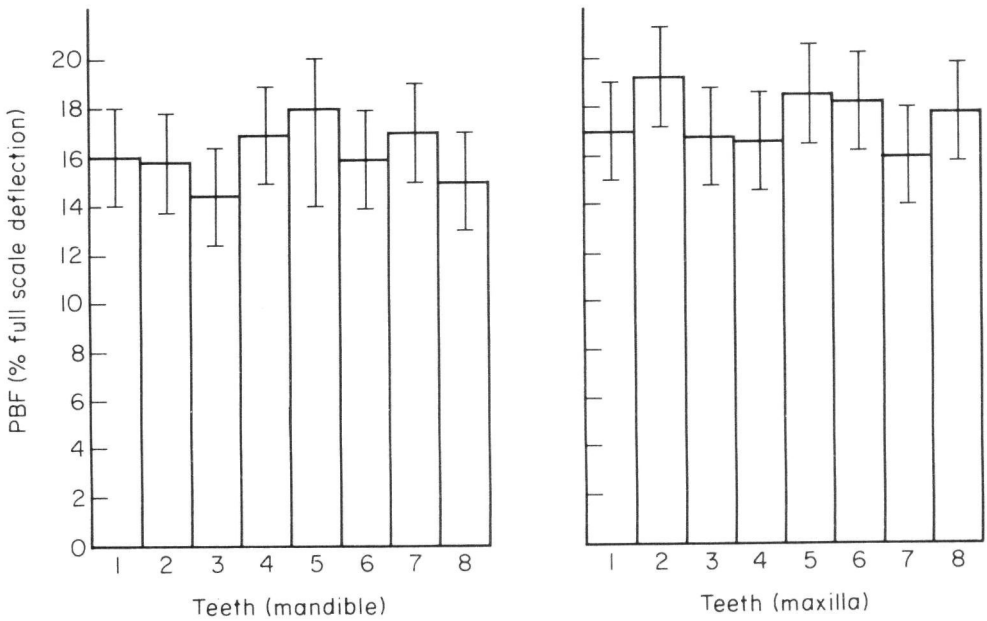


Fig. 1. Mean pulpal blood flow values in individual types of teeth; bars indicate standard deviation.

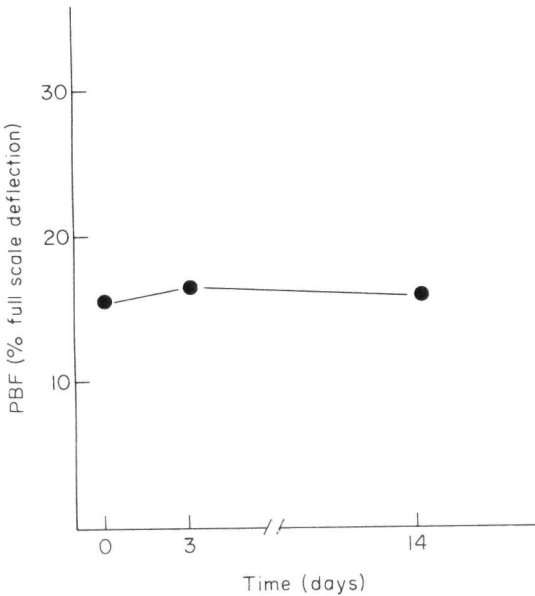


Fig. 2. Mean pulpal blood flow before and after treatment in 15 teeth with enamel caries.

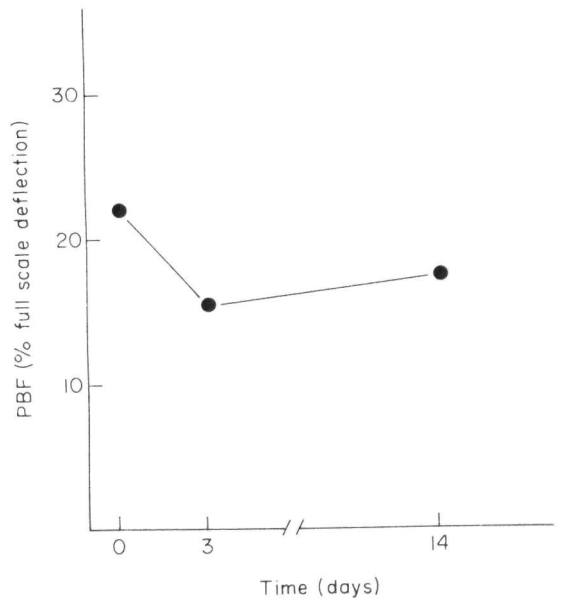


Fig. 3. Mean pulpal blood flow before and after treatment in 23 teeth with superficial dentine caries.

significantly from values in healthy teeth ($P < 0.01$). Three days after treatment, mean PBF levels had returned to normal (15.8 per cent FSD); they remained within this range (17.8 per cent FSD) 14 days after treatment (Fig. 3).

Compared with groups 1 and 2, initial PBF levels were significantly raised in the deep

dentine caries group ($P < 0.01$), measuring 28.7 per cent FSD. The assessment of PBF 3 days after treatment led to the division of this group into two subgroups, although clinically and symptomatically all the teeth were identical. In six of the 17 teeth, PBF levels remained at approximately the pre-treatment value;

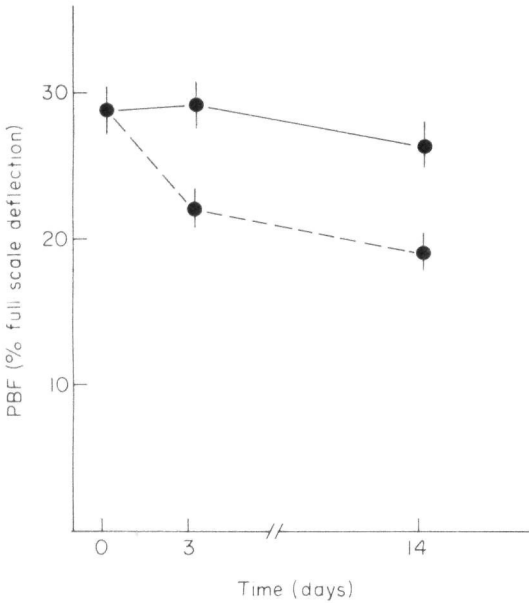


Fig. 4. Mean pulpal blood flow before and after treatment in 17 teeth with deep dentine caries. —, PBF in six teeth where level remained high; ---, PBF in 11 teeth where level fell by 3 days.

29.1 per cent FSD, no significant change ($P > 0.05$). Fourteen days post-treatment there was still no significant change, with PBF at 26.6 per cent FSD. The PBF of the other 11 teeth fell to 22 per cent FSD after 3 days, and after 14 days at 18.3 per cent FSD, it no longer differed significantly from levels in control teeth (Fig. 4). Two months later, the PBF in the 11 teeth which had reduced PBF at 14 days remained normal at 17.1 per cent FSD, and these teeth gave a vital response to thermal and electric pulp testing. In five out of six teeth which had shown no improvement in PBF 3 days and 14 days after treatment, blood flow had fallen to an average 3.7 per cent FSD; also three of these teeth no longer responded to electric and thermal stimuli. Yet none of these patients complained of any symptoms and radiographically no changes were apparent. The results are summarized in Figs 5 and 6.

Discussion

These studies were restricted to non-smokers to eliminate any possible vasoactive effects from this source. The measurements of PBF showed good reproducibility. A coefficient of variation of 8.9 per cent at individual sites lay

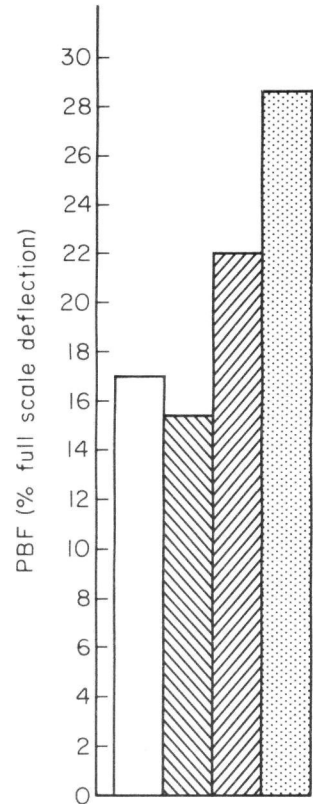


Fig. 5. Mean pulpal blood flow values in the following four groups of teeth before treatment: healthy teeth (▨), teeth with untreated enamel caries (□), teeth with untreated superficial dentine caries (▧), and teeth with untreated deep dentine caries (▩).

well within the ranges determined by other LDF-meter studies on microcirculation; Tenland (1982) calculated a value of 6 per cent in repeated measurements of a stable emulsion, while Smits *et al.* (1986) had an *in vivo* variation of 9 per cent. However, other authors assessing tissue perfusion have reported less favourable reproducibility of data (Shepherd *et al.* 1987), perhaps because these studies concerned blood flow in entire organs, where reproducibility would be significantly affected even by minimal changes in probe location, due to regional variations in microvascular density. Also, this method provides a high degree of spatial resolution for sampling blood flow in a small volume of tissue which may not be representative of general flow within an entire organ.

In the control group, PBF readings were taken from each tooth with the probe applied

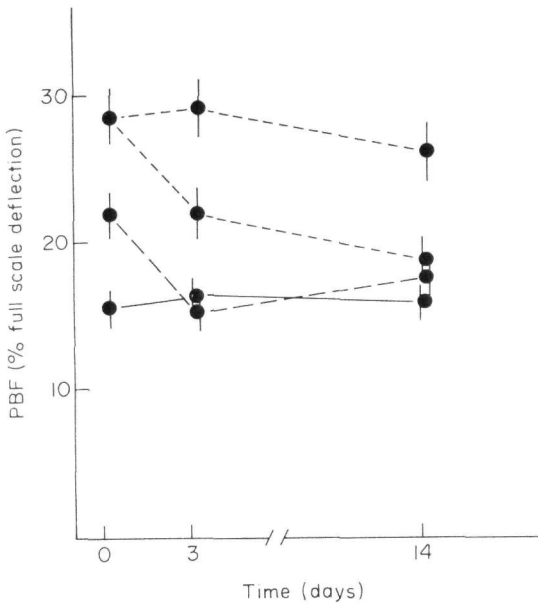


Fig. 6. Mean pulpal blood flow before and after treatment in the following three groups of carious teeth: teeth with enamel caries (—), teeth with superficial dentine caries (---), and teeth with deep dentine caries (· · · ·).

first mesially, then mid-buccally and finally distally, as it was impractical to position the measuring probe on each tooth in exactly the same site and at an identical angle each time.

These results confirm those of Damber *et al.* (1982), who attributed their observation that LDF measurements of testicular blood flow were not significantly affected by the probe/tissue angle, to the relatively large measuring area of the LDF meter. Perhaps no significant interpatient variations in PBF were apparent due to the careful matching for age and health of all patients included in this study as proposed by Stanley (1961). However, Zeghal *et al.* (1986) observed similar uniformity of results in the distal capillary network of the finger irrespective of age, weight, blood pressure and heart rate. Tönder (1980), also found that large differences in systemic blood pressure did not affect pulpal blood pressure levels in dogs and cats. She attributed this to compensatory changes in the balance between vascular resistance relative to intra- and post-pulpal resistance.

The observation that PBF in teeth with superficial caries affecting enamel did not

differ significantly from blood flow levels in sound teeth confirms histological investigations describing no pulpal changes under symptomless enamel lesions (Massler 1967), although a variety of factors appear to be involved in determining pulpal response to early carious lesions (Brännström & Lind 1965).

The measures for minimizing the trauma of treatment were shown to be successful as PBF levels in teeth with enamel caries remained constant before and after treatment. A raised PBF level in teeth with superficial dentine caries parallels the results of histological investigations (Yoshida & Massler 1964, Brännström & Lind 1965, Massler 1967) demonstrating inflammatory reactions under active lesions of this type, with the exact degree of pulpal response depending on a multitude of factors, e.g. present type and state of activity of lesion and of cariogenic microorganisms, whether underlying dentinal tubules are open or sclerosed, and the remaining thickness of dentine. As PBF levels had already returned to normal 3 days after treatment, it appears that the inflammatory reaction within the pulp abated once carious dentine had been removed. This finding is in agreement with functional studies by van Hassel (1971), Mjör & Tronstad (1974) and Tönder (1983), who indicated that, provided inflammation was not too extensive and pulpal damage remained relatively localized, the pulp has considerable reparative potential and PBF levels should rapidly return to normal via local compensatory mechanisms.

Teeth with deep dentine caries demonstrated the greatest rise in PBF, again confirming results of histological investigations showing pulpal inflammation under deep dentine caries, and correlating, amongst other factors, advanced carious destruction with increasing severity of pulpal reaction (Brännström 1960, Massler 1967, Stanley 1970).

The decreasing PBF in 11 teeth, 3 and 14 days after treatment, was presumably a sign of resolution of pulpal inflammation, confirmed by the return of all these values to normal within 2 months. In the six other teeth, lack of improvement in PBF level 14 days after treatment was attributed to spreading

inflammation and pulpal damage. This was verified 2 months later, when five of these teeth demonstrated only minimal PBF levels, and three of them no longer showed any response to electric and thermal stimuli.

Conclusion

From these preliminary investigations it appears that pulpal blood flow can be assessed reliably by laser Doppler flowmetry. These measurements augment clinical observations, providing an improved basis for dental treatment planning.

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