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Possible application of transmitted laser light for the assessment of human pulp vitality. Part 2. Increased laser power for enhanced detection of pulpal blood flow

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Abstract – The purpose of this study was to investigate the effect of an increase in laser power on the transmitted laser signals from vital and non-vital teeth, in the hope of achieving a better assessment of human pulp vitality with the transmitted laser-light flowmeter. The experiments were carried out on total of 61 vital teeth with no restoration (19 upper central incisors, 16 upper lateral incisors, 16 upper canines, and 10 first premolars) and five non-vital upper central incisors (the root canals of which were filled with gutta-percha) in 15 subjects aged 22–28 years. For use with transmitted laser light, the fibers within the probe of a conventional laser Doppler flowmeter (LDF) apparatus were used, one for transmitting light onto the labial surface, the other for receiving it at the palatal surface of the same tooth, as reported previously. Laser output power was set at the original 2 mW and also at 5, 7, and 10 mW. The number of vital teeth displaying a blood flow (BF) signal at each laser power setting was: 1) 12/19 central incisors at 2 mW, 19/19 at 5, 7, and 10 mW, 2) 19/19 lateral incisors at 2, 5, 7, and 10 mW, 3) 0/16 canines at 2 mW, but eight, 12, and 14 at 5, 7, and 10 mW, 4) 0/10 first premolars at 2, 5, 7, and 10 mW. Thus, an increase in laser power increased BF detection from the thicker teeth (but not from premolars). In addition, clearer BF signals synchronized with heart rate, and greater passive BF changes secondary to blood pressure (BP) changes were observed at higher laser settings. In non-vital teeth, no signals synchronized with heart rate or BP changes were observed, indicating that no BF signal of non-pulpal origin was ever monitored with this ballistic light even when the laser power was increased. These results indicate that high-powered transmitted laser light could be a useful tool both for monitoring pulpal BF and for the assessment of tooth-pulp vitality.

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Key words: transmitted laser light; pulpal blood flow; laser Doppler flowmetry; pulp vitality test

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Pulp-vitality testing should form an integral part of oral diagnosis, as a means of distinguishing or identifying disease. However, the most widely used methods, such as electrical and thermal tests, determine not pulp vitality, but rather pulp sensitivity to the stimuli used. Consequently, false

responses may be obtained from traumatically injured teeth or from immature teeth (1–5). Furthermore, such tests cause pain to the patient, and therefore have a subjective element. It is of much greater importance to determine whether the circulation is intact in the dental pulp. In this connection, laser Doppler flowmetry (LDF), developed in the 1970s to measure the velocity of red cells in skin capillaries, has been introduced for the diagnosis of pulp vitality in human teeth (6–9). To obtain clearer signals from the dental pulp, some investigators have modified LDF by altering the wavelength of the laser light (to vary the depth of penetration into the tissue), the bandwidth (to reduce signal noise), and the design of the probes (10–12). It has been shown that the LDF output signal from a non-vital tooth is significantly lower than that from a vital tooth, but those from non-vital teeth do not usually register as zero. For this reason, it has been suggested that part of the signal recorded from the enamel surface actually derives from blood flow (BF) in tissues outside the pulp (i.e. BF of non-pulpal origin) (13–15), and indeed transmitted or back-scattered laser light is reflected in a complicated way around the dental pulp. In a previous study in which we attempted to circumvent this problem, we made a comparison of transmitted laser light and back-scattered light (usual laser Doppler method: LDF) for the assessment of human pulpal vitality in the upper central incisors (16). In that study, we found: 1) in non-vital teeth, output signals with the transmitted laser-light system all registered as zero, and no oscillations could be observed in recordings from any location on the tooth, whereas LDF signals were above zero, and there were regular oscillations related to heart rate, as well as passive increases in BF secondary to blood pressure (BP) increases, indicating that LDF registered BF of non-pulpal origin; 2) in vital teeth, the output signals with transmitted laser light were about twice the amplitude of those seen with LDF, and passive BF changes secondary to BP increases were more clearly observed with the former than with the latter system. Consequently, we concluded that transmitted laser light might be useful for the assessment of tooth pulp vitality both because the BF signals did not include flow of non-pulpal origin, and because its output signals and response to BF changes were clearer and could easily be monitored (16). However, when this prototype apparatus was clinically applied to all teeth, we discovered that the output signals from some vital teeth with thick dentin often registered as zero. Hence, a further improvement in the apparatus was clearly needed to allow photons to penetrate more deeply and pass straight through the tooth towards the receiving fiber. To date, no studies have investigated how the BF signal from the dental pulp changes when the laser power is altered, although it is widely known that an increase in laser power (increase in photon density) prevents an attenuation of light force. The present study addressed this situation by investigating the effect of increases in laser power on the signals recorded from a sample population of vital and non-vital human teeth.

Material and methods

The experiments were carried out on a total of 66 teeth in 15 subjects aged 22–28 years. Of these 66 teeth, 61 were vital teeth with no restoration (19 upper central incisors, 16 upper lateral incisors, 16 upper canines, and 10 first premolars) all of which showed a vital response to an electrical pulp tester (Model 2002; Vitality Scanner, Analytic Technology Corporation, Redmond, WA, USA) at normal threshold, and five were upper central incisors that were non-vital, to judge from radiographic evidence, and had root canals filled with gutta-percha. The study received local ethics committee approval, and informed consent was obtained from all subjects.

For all tests, we modified a conventional LDF (Laser flowmeter ALF 21D; Advance, Tokyo, Japan), which normally emits a 2 mW low-intensity beam of monochromatic light from a laser diode, in such a way as to increase its laser output power to 5, 7, or 10 mW. In this apparatus, when the scattered light measured on the photo-detector is less than 0.005 μW, the measuring display registers zero and a green lamp lights up on the front panel because the signal/noise (S/N) ratio has dropped and the power spectrum cannot be normalized. The LDF probe comprises two glass graded-index optical fibers, one transmitting and one receiving, each with a core diameter of 100 μm. When we used transmitted laser light, we used a single probe, one fiber of which acted as the transmitter on the labial side of the tooth, while the other (having been led to the palatal side) acted as the receiver, as described previously (16).

Before monitoring BF, we made a plaster model (dental cast) of each subject's upper jaw, and placed a plastic splint of 3 mm thickness on the plaster model, covering all the upper teeth, including the palatal side. Then, we made a hole straight through from the labial side to the palatal side. Transmitting and receiving fibers were located at the labial and palatal holes, respectively, and the relationship between these fibers at each location was consequently kept rectilinear at the same level and height (approximately at the center of the tooth crown), as described previously (16) (Fig. 1). Zero calibration for BF was performed in each experiment using the

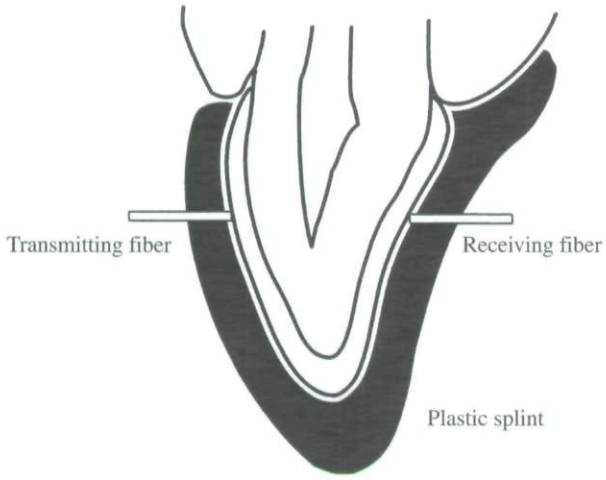

Fig. 1. Schematic drawing of the transmitted-laser system for monitoring pulpal blood flow. Transmitting and receiving fibers, located roughly at the centers of the labial and palatal tooth crowns, respectively, were fixed in position by means of a plastic splint.

mechanical zero-calibration mode inside the apparatus itself. The systemic BP of each subject was monitored from the left forefinger by means of a non-invasive pressure transducer (Finapres; Ohmeda, Louisville, KY, USA). The output signals for BF (0–10 mV) and BP (0–200 mmHg) were continuously and simultaneously recorded (Recti-Horiz-8K Recorder; NEC, Tokyo, Japan). In this experiment, we obtained increases in BP by asking subjects to hold their breath and contract their stomach muscles for 10-s periods. We did this because of our previous report indicating that pulpal BF is strongly dependent on systemic BP (17).

Results and discussion

Table 1 summarizes the number of teeth displaying BF signals when transmitted laser light was used at different laser output power settings, together with the BF output signals (expressed as mean ± SD in mV) and tooth thickness (expressed as mean ± SD in mm, for the labio-lingual thickness of each kind of tooth through which the transmitted laser light passed). As laser power was increased, the number of teeth that displayed BF signals increased among the vital-teeth. In detail: 1) 12/19 (63.2%) central incisors displayed BF signals at 2 mW laser power, and all 19 displayed BF signals at 5, 7, and 10 mW, 2) 19/19 lateral incisors displayed BF signals at 2, 5, 7, and 10 mW, 3) 0/16 canines displayed a BF signal at 2 mW laser power, but eight (50%) did at 5 mW, 12 (75%) did at 7 mW, and 14 (87.5%) did at 10 mW, and 4) 0/10 first premolars displayed a BF signal at 2, 5, 7, or 10 mW.

As can be seen, thicker teeth did not show a BF signal when laser power was weak (output signals registered as zero in these cases). For this reason, we consider that thick dentin prevents the photons from penetrating deeply and passing straight through the tooth towards the receiving fiber. Indeed, it is already known that due to the extremely strong multiple scattering that occurs in most biological structures, only a very small proportion of the light incident on a tissue surface will penetrate very deeply, even when adequate wavelengths are used in the range 600–1200 nm (a range within which absorption by biomolecules is relatively weak) (18). Historically, a 5 mW laser was used on a commercial basis as a light source for LDF (19), but with the improvements in signal-to-noise ratio that occurred over the first few iterations of the LDF system, an adequate signal could be obtained with a 2 mW helium-neon or diode (20). However, LDF was originally developed for the measurement of BF in the skin, in which capillaries are much closer to the surface than in the dental pulp. Hence, the widely used laser power (2 mW) is insufficient for detecting pulpal BF with transmitted laser light (at least with the present apparatus).

Typical recordings made in the present study are shown in Fig. 2. With increases in laser power, the BF signals were augmented, and passive BF changes secondary to BP changes were more clearly observed in the vital teeth. Increased laser power

Table 1. Number (percentage) of teeth displaying blood flow signals with transmitted laser light at different laser output powers, amplitude of blood flow output signal (mV), and tooth thickness (mm) for each kind of tooth

	Number of teeth displaying blood flow signal				Amplitude of blood flow signal (mV)				
Laser power (mW)	2	5	7	10	2	5	7	10	Tooth thickness (mm)
Vital teeth									
Central incisor	12/19 (63.2)	19/19 (100)	19/19 (100)	19/19 (100)	6.3 ± 2.6	7.2 ± 2.1	10.5 ± 2.4	12.7 ± 3.4	4.4 ± 0.7
Lateral incisor	16/16 (100)	16/16 (100)	16/16 (100)	16/16 (100)	7.1 ± 1.6	9.4 ± 0.9	11.8 ± 2.6	15.1 ± 3.3	3.9 ± 0.5
Canine	0/16 (0)	8/16 (50)	12/16 (75)	14/16 (87.5)	0	4.6 ± 2.3	5.7 ± 1.9	7.4 ± 3.8	5.6 ± 0.8
First premolar	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0	0	0	0	9.4 ± 0.9
Non-vital teeth									
Central incisor	0/5 (0)	0/5 (0)	0/5 (0)	0/5 (0)	0	0.4 ± 0.3	1.2 ± 0.8	3.0 ± 2.1	4.6 ± 0.5

Values in parentheses are in percentage.

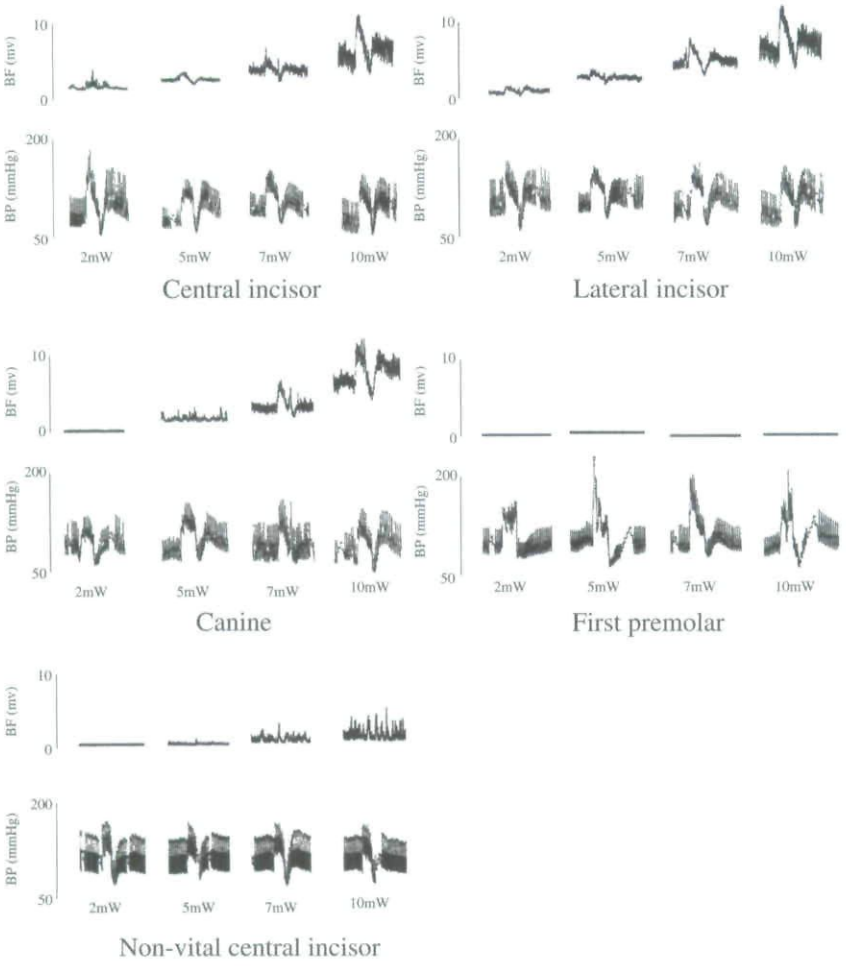

Fig. 2. Original output-signal recordings (BF) obtained using transmitted laser light with laser output power setting of 2, 5, 7, or 10 mW from vital and non-vital teeth, together with systemic blood pressure (BP) recordings. With increases in laser power, BF signals were augmented, and the passive BF changes secondary to BP increases were more clearly observed in the vital teeth (except the first premolar). Increased laser power also amplified the irregular oscillations, as noise, in the non-vital tooth.

also amplified the irregular oscillations (as noise) in the non-vital teeth, probably due to widespread scattering of laser light, which interfered with accurate calculation of the power spectrum. However, such noise could be easily identified because it was never synchronized with heart rate or with BP changes at any laser power, indicating that BF of non-pulpal origin was not being monitored with this ballistic light, even when the laser power was increased.

To judge from the above observations, transmitted laser light at increased laser power should be useful for monitoring pulpal BF and for the assessment of tooth pulp vitality, both because the BF signals do not include flow of non-pulpal origin and because the output signals and response to BF changes can clearly be monitored from the thick anterior teeth. However, even transmitted laser light was unable to detect pulpal BF in the first premolars within the range of laser powers used here, and much stronger laser powers cannot be tested at present because of Japanese Industrial Standard (JIS) restrictions as to the use of lasers. With further development of the apparatus, to allow it to be applied to the posterior teeth and to be used freehand (without firm fixation of the optical probe), this instrument might become a valuable clinical tool.

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