Pulpal blood flow in vital and nonvital young permanent teeth measured by transmitted-light photoplethysmography: a pilot study

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Abstract

Purpose: The purpose of this study was to record transmitted-light photoplethysmography (TLP) from young permanent teeth and examine its applicability to pulp vitality assessment.

Methods: Twenty-six healthy and 7 nonvital upper maxillary incisors in 17 children (ages 7 years, 3 months to 14 years, 8 months) were examined. Recordings of TLP were made with and without opaque black rubber dam application in a darkened room. Finger photoplethysmography (FPP) of the participants was simultaneously recorded.

Results: (1) Pulse waves synchronous with FPP were recorded from all healthy teeth, whereas no pulse signals were recognized in nonvital teeth. (2) The signal amplitude in the TLP was not significantly affected by the opaque dam application. (3) In the healthy teeth, there was a significantly negative correlation between the TLP pulse amplitude and the age of the subjects.

Conclusions: TLP can detect pulpal blood flow in young permanent teeth. This technique is considered to be applicable in the assessment of pulp vitality. (*Pediatr Dent*. 2002;24:594-598)

KEYWORDS: PULP, PHOTOPLETHYSMOGRAPHY, PERMANENT TEETH, VITALITY TEST, PULP DIAGNOSIS

Received May 1, 2002 Accepted August 26, 2002

The vitality of the tooth pulp in adult humans is generally determined by clinical examinations such as visual examination, radiographs, electric pulp tests, and thermal tests.[1,2] In these methods, electric pulp testing is well accepted because the response to electrical stimuli can be semiquantitatively evaluated and is comparable within teeth and subjects. For immature permanent teeth, however, inaccuracy of the response to electric and thermal stimuli to the pulp has been reported.[3-5] In addition, these examinations inevitably elicit pain, which may be uncomfortable for young patients and may affect further dental treatment.

Recently, the determination of the pulp vitality in traumatized teeth has been reported by means of a laser Doppler flowmeter (LDF).[6-11] While this method has the advantages of being objective and painless, it has been reported that LDF signals contained an artifact component which was derived from periodontal blood flow and did not accurately reflect pulpal blood flow (PBF).[12-14] This artifact is considered to be produced by the scattering of laser light through a wide area of the tooth surface.[15]

Transmitted-light photoplethysmography (TLP) is one of the noninvasive techniques to monitor PBF, in addition to LDF, and has been applied to the pulp in cats,[16,17] dogs,[18] and adult humans.[19-26] It has been suggested that TLP has the advantage of less signal contamination derived from periodontal blood flow than that recorded by LDF.[13] However, no study on the use of TLP in young permanent teeth in humans has been conducted. Therefore, the aim of this study was to examine the effect of dam application on TLP and the clinical applicability of TLP as a device for monitoring pulpal blood flow in young permanent teeth.

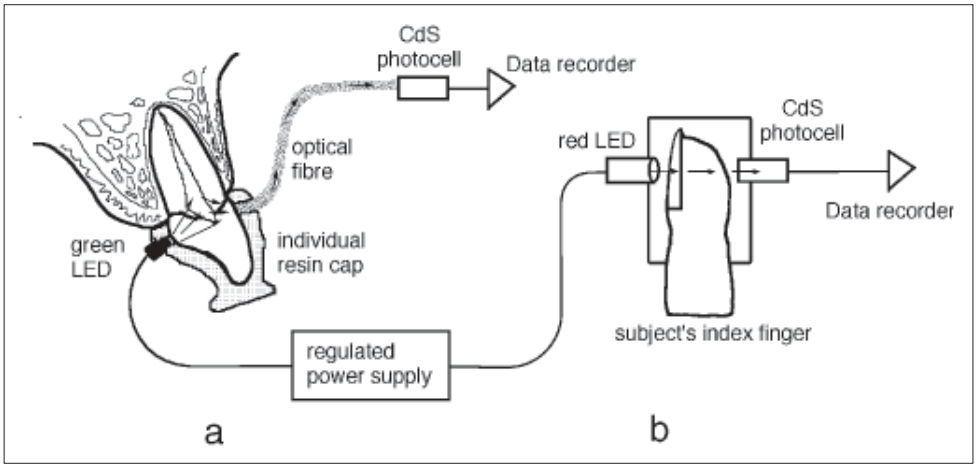

Fig 1. Schematic drawings of TLP (a) and FPP (b) recordings from the subject

Methods

Subjects and examined teeth

This study was approved by the Ethical Committee of the Graduate School of Tokyo Medical and Dental University. Examined were 26 healthy maxillary central incisors in 13 children (ages 7 years, 3 months to 14 years, 8 months; mean=11 years, 9 months), 7 nonvital teeth, 1 root-canal-filled tooth (11 years, 7 months) and 6 other teeth confirmed as pulp necrosis by endodontic treatment (10 years, 7 months to 13 years, 3 months; mean=11 years, 8 months). Prior to the investigation, the procedures, possible discomforts, and benefits were explained fully to the subjects and their parents, and informed consent was obtained.

Prior to the recording, an individual resin cap was prepared for each tooth from a plaster model of the upper tooth arch of each subject so as to cover the labial and the palatal surface of the tooth examined.[23,24] Holes 2.4 mm in diameter and with their centers approximately 2 mm from the gingival margin were drilled in the cap—1 labially and 1 palatally—at right angles to the mesiodistal center of the tooth surface.

Light source and photodetector

The light source (Fig 1) was a green LED (peak power at 525 nm; NSPG 500 S, Nichia-Gosei Kagaku Corp, Tokushima, Japan) driven by a regulated power supply. The tip of the LED was trimmed down to a diameter of approximately 1.5 mm and enclosed in a short length of stainless-steel tube (outer diameter 2.4 mm) which, in turn, was fitted in the palatal hole of the individual resin cap. Light transmitted through the tooth being examined was detected using an optical fiber (type EHV 4001, Mitsubishi Rayon Co, Tokyo, Japan; outer diameter including the covering 2.2 mm, fiber diameter 1.0 mm) placed in the buccal hole of the cap. The light was then transmitted to a CdS photoconductive cell (type MKY4H-38, Moririka Electronics Ltd, Yokohama, Japan; peak sensitivity=560 nm), which was connected either to a resistance meter or to 1 arm of an AC-coupled Wheatstone bridge (bandpass 0.5-15 Hz). In each subject, the average resistance of the photoconductive cell was measured to adjust the equilibrium resistance of the Wheatstone bridge. Transmitted-light intensity changes due to the pulse blood flow in the pulp were transformed as changes in the resistance of the photoconductive cell and recorded as TLP.

Recording procedure and rubber dam application

Each subject was placed in a supine position and the lips were retracted. An opaque black rubber dam (Four D Rubber Co Ltd, Heanor, Derbyshire, United Kingdom; thickness 0.25 mm) was applied to the tooth being examined and to the adjacent teeth to examine its effects on eliminating signals derived from periodontal blood flow. The individual resin cap was fitted to the test tooth and was retained using a small amount of dental cement (Dycal, The LD Calk Division, Dentsply International Inc, Milford, Del) along the incisal edge, if necessary. The optical fiber and the LED were inserted tightly into the buccal and palatal holes, respectively, of the cap until the tips touched the tooth surface. The room light intensity was reduced, and TLP was recorded for about 3 minutes with the dam in place. Simultaneously, finger photoplethysmography (FPP) was recorded. The dam was then removed using scissors without disturbing the optical fiber or the LED tip in the cap, and recording was resumed. This procedure was then repeated for the second tooth examined for the same subject. TLP signals were afterwards averaged (N=16) using a personal computer (Power Macintosh G3, Apple Computer Inc, Cupertino, Calif) and a laboratory interface (PowerLab, ADInstruments Pty Ltd, Australia). From these averaged records, the mean value of the peak-to-peak amplitudes (volts) of the pulses in TLP signals were measured.

Statistics

The effect of dam application on the signal amplitudes of the TLP pulse waves was examined by the Student's paired *t* test. Correlations between TLP pulse amplitudes (volts) and the subjects' ages (years) were measured by calculating the Pearson correlation coefficient. TLP signal amplitudes were compared between the vital teeth and the nonvital teeth using Mann-Whitney U-test. A *P* value less than .05 was taken as indicating statistical significance.

Results

Figure 2 shows a recording of FPP and TLP with dam in place from a healthy tooth (subject age=13 years, 3 months). The pulse waves synchronous with FPP were recognized in all healthy teeth both with and without dam application. In the healthy teeth, the dam reduced TLP pulse amplitudes in 17 of the 26 teeth ranging between -33% and 26% (mean±SD, 5.6±18%), however, this change was not significant (P=.106, Student paired t test). Figure 3 shows a recording of FPP and TLP with dam application from a nonvital tooth (subject age=7 years, 7 months). This tooth was confirmed as pulp necrosis by endodontic treatment done after the recording. No pulse waves synchronous with FPP were observed. This was also the case with 7 other nonvital teeth, including a root-canal–filled tooth. Figure 4 is a scattergram that shows the relationship between the TLP signal amplitudes and the age of the subjects. In the vital teeth, there was a significant negative correlation between the pulse amplitudes in the TLP signals in individual teeth and the age of the subjects with the dam (N=26, R=-0.450, P=.020, Pearson correlation coefficient) and without the dam (N=26, R=-0.453, P=.019, Pearson correlation coefficient). When the signal amplitudes were compared between the vital teeth and the nonvital teeth for the ages 10 years, 7 months to 13 years, 3 months (vital N=14, nonvital N=7), the pulse amplitude in the vital teeth was significantly higher than that in the nonvital teeth (P=.0003, Mann-Whitney U-test).

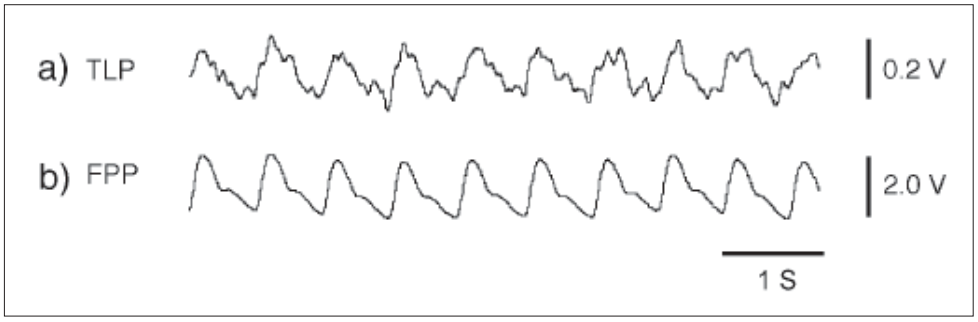

Fig 2. TLP (a) from a vital tooth of a subject (age 13 years, 3 months) and FPP (b)

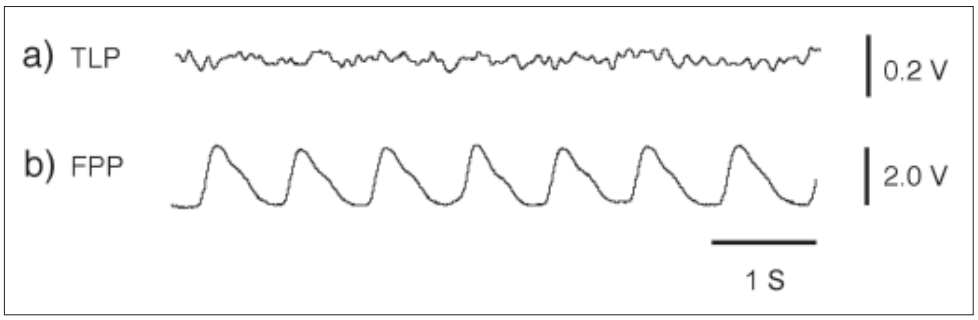

Fig 3. TLP (a) from a nonvital, upper left central incisor and FPP (b) of a subject (age 7 years, 7 months). The recordings were made at 3 weeks after the injury.

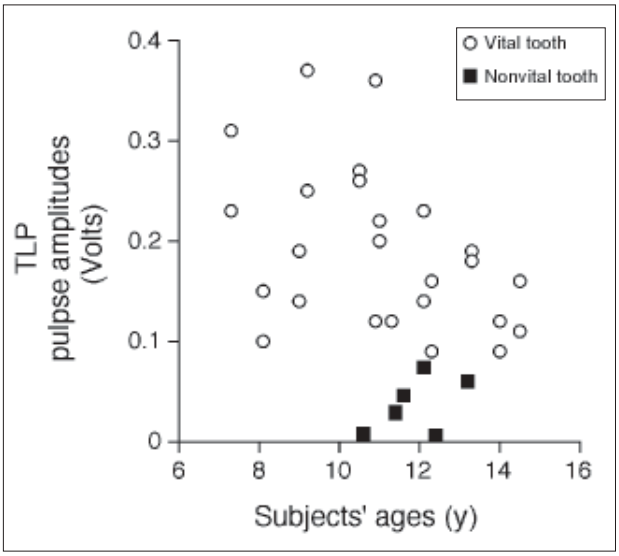

Fig 4. A scattergram representing the relationship between the amplitudes of pulse wave (volts) and the subjects' ages (years). The ordinate and the abscissa represent pulse wave amplitudes (volts) and the subjects' ages (years), respectively. Data were obtained from the healthy teeth (open circles) and the nonvital teeth (filled squares) with the dam in place. Several data points in both groups are so close that they are not distinguishable from each other.

Discussion

The result that TLP was recognized in all the healthy teeth but not in nonvital teeth suggests that TLP detects pulpal blood flow in young permanent teeth. It has been previously reported that TLP, using a similar arrangement of light source and detector, detected mainly pulpal blood flow.[21,22] According to a study by Ikawa et al,[23] pulse waves were not recognized in 1 of 8 examined teeth of adult subjects. Although a comparison of TLP between young and aged permanent teeth has not been made, it is suggested that it is easier to detect TLP from young subjects, where abundant PBF is expected, than from elderly or adult subjects. At present, the TLP method should be applied to pulp vitality assessment where precise quantitative measurements are not necessarily required.

While the opaque rubber dam was reported to reduce 70%-80% of the signals recorded by LDF,[12-14] TLP signals were not significantly reduced by the dam application. This supports previous findings[13] that TLP has the advantage over LDF of less signal noise derived from periodontal blood flow. This may be in part due to the pathway of the light (ie, collection of the transmitted light through the tooth is considered to be less contaminated by the light that scatters outside the tooth and then comes into the tooth than

collecting the reflected light). Roebuck et al[27] suggests that the use of transmitted laser light[28] may be of use when using LDF as a diagnostic tool.

There was a negative correlation between the pulse amplitudes in the TLP signals in the healthy individuals and the age of the subjects. This is considered to be due to the difference in the size of the pulp chamber and PBF between the subjects, and may suggest that the TLP signals also reflect the status of the root development of the tooth. With a significant relationship between the TLP signal and the status of root formation, radiographic examinations could be to some extent replaced by TLP, which would reduce exposure to x-rays and benefit patients. At present, the available information is limited and a definite conclusion is not drawn. However, this merits further study.

To date, when reviewing published reports on the use of TLP to record blood flow in the human dental pulp, no study has detailed the repeated measurement of TLP over a long period in the same subjects. We prepared an individual resin cap in the present study, which would enable exactly the same positioning of the LED and the optical fiber and allow the repeated measurement of TLP. This suggests the potential usefulness of TLP as a repeated assessment of the pulp vitality in traumatized teeth.

Conclusions

TLP can detect pulpal blood flow in young permanent teeth. This technique is considered to be applicable to the assessment of pulp vitality.

Acknowledgments

This study was supported by a scientific research grant from the Ministry of Education in Japan (No. 10671929) to Zenzo Miwa. We are grateful to D. Mrozeck for English proofreading of this manuscript.

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Abstract of the Scientific Literature

Incidence of Supernumerary Teeth and Isolated Cleft Lip

The purpose of this study was to observe the incidence of hypo/hyperdontia and nasal floor height in patients with isolated cleft lip (no cleft through the alveolus). This retrospective record evaluation used 30 patients with soft tissue lip clefts who were randomly selected from patients who presented to the Department of Maxillo-Facial Surgery and Jaw Orthopedics and compared to 30 randomly selected individuals matched for age that presented to the Department of Orthodontics, both at Malmö University, Sweden. The position of the floor of the right and left nasal cavity was determined to the nearest 0.5 mm and the difference between sides was calculated within each patient (right to left) and compared to controls using student's *t* tests. The presence or absence of the lateral incisors and supernumerary teeth were recorded from records of each subject and correlated with nasal floor distance differences. The authors found that the vertical position of the nasal floor differed significantly between the cleft and noncleft sides ($P < .001$) and that supernumerary teeth were found in 73% (primary and/or permanent; 40% had supernumerary teeth in both dentitions) of the cleft subjects but were completely absent in the control group. There were no missing laterals found in either group. The authors concluded that isolated cleft lips were usually associated with a lowering of the nasal floor on the cleft side and the presence of supernumerary primary or permanent lateral incisors on the cleft side.

Comments: Although this admittedly was a small study, the authors found a very high incidence of supernumerary teeth in individuals with only a soft tissue cleft of the lip. This included clefts that were incomplete and complete but not involving the alveolar process where interruption in the dental lamina is obvious. It would be interesting to determine in a larger study and within other ethnic populations if this very high incidence is maintained. **DARB**

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Hansen, K, Mehdinia, M. Isolated soft tissue cleft lip: the influence on the nasal cavity and supernumerary laterals. *Cleft Palate Craniofac J*. 2002;39:322-325.

16 references