Evaluation of a laser Doppler flowmeter to assess blood flow in human primary incisor teeth

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Abstract

Purpose: *This study determined whether the portable Advance Laser Flowmeter Model 21®, a clinical instrument, would indicate significant values when pulpal blood flow was present or absent; whether the analog output of the flowmeter was time-linked to the heart rate; and whether labial and lingual crown surfaces produced different flow values.*

Methods: *Teeth were tested under two conditions: with the teeth in situ and extracted, or with the pulp present and removed.*

Results: *Values before and after the teeth were extracted, and those before and after pulpectomy with the tooth in situ were significantly different. These findings verified that the flowmeter measured the presence of bloodflow. Peaks of the electrocardiogram waves and the regular signal flucuations of the flowmeter were time-linked and verified the measurement of the heart rate from the dental pulp. Differences in the values for the lingual and labial surfaces of individual teeth were not significant.*

Conclusions: *This instrument proved a valid means of determining the presence of pulpal blood flow in primary incisors. (Pediatr Dent 21:53–56, 1999)*

Neural stimulation methods used to evaluate the vascular integrity of teeth produce painful stimuli that are often unacceptable to young children. Nevertheless, children frequently require such evaluations because of the sequelae of dental trauma or caries that affect the pulpal vasculature of primary teeth. Chambers[1] suggested that the ideal technique for the evaluation of dental pulp status must be noninvasive, objective, painless, inexpensive, reliable, reproducible, standardized, and easily completed.

Currently, the only indicator of dental pulp status that fits most of these criteria is the periapical radiograph, a late indicator of vascular integrity, since radiographic changes are associated with pulpal necrosis.[2] Neural-stimulation methods rely on an indirect measurement of vitality, the failure of neural conduction, which is also a late indicator of pulpal necrosis, even though nerve fibers degenerate at about the same rate as other pulp tissues.[3] The use of both radiographic and neural stimulation methods is based on the knowledge that partial necrosis of neural and other pulp tissues may coexist with early radiographic evidence of pulpal necrosis at the root apex.[3] An additional variable is present for neural-stimulation tests in primary teeth since their neural sensitivity varies with the stage of root development and resorption.[4]

The laser Doppler flowmeter, developed in the 1970s to measure the velocity of red blood cells in capillaries, is a noninvasive, objective, painless alternative to traditional neural-stimulation methods, and therefore a promising test for young children. This flowmeter has been successfully used to monitor blood flow in the tooth pulp of cats, rats, and humans, both noninvasively and instantaneously.[5, 6] Edwall et al.[5] showed that measurements taken with a flowmeter in cats and rats were comparable to those taken with local 125I-clearance methods and were not altered by periodontal or gingival blood flow. In a study of adult human dental pulp, Gazelius et al.[6] found that the flowmeter could produce a signal that would allow the differentiation of healthy from nonvital teeth. The flowmeter produced regular signal fluctuations for vital teeth that were identical in rate to electrocardiogram (ECG) waves. Nonvital teeth showed no such synchronous signal, but produced irregular fluctuations or very steep spike traces that were attributed to movement artifact. This instrument has demonstrated its value for ongoing assessment of post-traumatized permanent incisors.[7, 8] Although the laser Doppler flowmeter's qualities appear ideal for the evaluation of blood flow in primary teeth, it has not been evaluated previously for this purpose.

The purpose of this investigation was to evaluate the suitability of a laser Doppler flowmeter for the assessment of blood flow in primary incisor teeth that are commonly affected by luxation and subluxation injuries.[9]

Methods

Thirty-two children, aged 14 months to 7 years, who were scheduled for restorative treatment under general anesthesia at The Hospital for Sick Children in Toronto, Canada, were randomly selected over a four-month period. The number of incisors tested per child ranged from one to four; all had preexisting dental caries. For inclusion in the study, all children were required to be healthy and to have maxillary primary incisors that had radiographic evidence of at least two-thirds of their roots. The incisors were scheduled for either extraction or root canal treatment. At this hospital, carious exposures of primary teeth with vital pulps are managed by a zinc oxide/ eugenol root canal treatment rather than the aldehyde-based vital pulpotomy that is the norm in North America.

Teeth were classified into one or more of three categories according to the patient's treatment plan: Category I, measurement of the labial and lingual surfaces of each tooth; Category II, measurement before and after extraction of each tooth; and Category III, measurement before and after pulp extirpation and obturation (root canal treatment). Not all teeth could be included in Category I since some teeth did not have sufficient surface area on both the labial and lingual surfaces to ensure that there would not be any false positive readings from gingival blood vessels (>2 mm).[10]

The teeth were measured with the flowmeter and the electrocardiograph described below under two different conditions (with and without blood flow) for one of the following variables: before and after extraction, or before and after root canal treatment.

The pulpal blood flow of each primary incisor was measured with an Advance Laser Flowmeter Model 21® (ALF 21; Transonic Systems, Ithaca, NY) and a hand-held DN-J (Transonic Systems) fiberoptic probe. In addition, cardiac electrical activity was monitored with a Hewlett-Packard Electrocardiograph (ECG) Model 78315A (Hewlett-Packard, Camas, WA) and four 3M ECG leads (3M, St Paul, MN) placed on the patients' right and left arms and legs. The displays of both the flowmeter and the ECG were recorded and printed with an eight-channel Graphtec Thermal Arraycorder (Graphtec, Tokyo, Japan).

All teeth were tested and radiographed intraoperatively. The following procedure was completed for teeth in Category I and for all teeth in Categories II and III before treatment. The end of the DN-J probe was placed on the cingulum (and also on the labial surface in the case of teeth in Category I) and directed toward the pulp chamber of the tooth. The fiberoptic probe was placed at least 2 mm from the gingiva to avoid soft-tissue interference.[10] Once the flowmeter output stabilized, tooth and patient identification data, probe surface, and flowmeter values were noted on the tracing. Once the pulpal blood flow was measured and recorded, treatment was completed and the incisors were remeasured. For teeth in Category I, both labial and lingual measurements were completed during the initial testing. For those in Category II, the extracted tooth was cleaned and held securely while the probe was placed on the lingual surface as before. For those in Category III, after completion of pulp extirpation and obturation, and before placement of the final resin restoration, the tooth was retested on the lingual surface.

To verify that the recordings were a measure of blood flow through the dental pulp, the analog display of the flowmeter was recorded and compared with the ECG tracings.[11, 12] Two values were obtained for each tooth. Each value consisted of a two-channel tracing and the value of the laser Doppler flowmeter. The only alteration during the measurements of the teeth in Categories II and III wasthe severed connection of the blood vascular system.

The tracings were analyzed in two ways. A random sample of 54 recordings from vital teeth taken before pulp extirpation or extraction was used. First, it was necessary to test for the time linkage of the flowmeter recording of pulpal blood flow pulse with that of the ECG. The number of peaks in the ECG recording representing the R-point of the wave and the pulsatile peaks recorded by the flowmeter were counted over a 10- or 15-sec period.

Since the ability of an observer to determine the presence of vascular integrity from the flowmeter display is essential if the equipment is to be used to make valid diagnoses, we determined whether outside observers could differentiate between readings taken before and after pulp extirpation or extraction. Forty sections of randomly selected recordings were duplicated and coded. Two independent observers, one dentist and one lay person who was not a health care provider, were asked to state whether the reading was taken from a vital pulp or a nonvital (pulp extirpation and obturation or extraction) pulp.

The Shapiro-Wilk test was used to measure the normality of values obtained for teeth in Category I; these values were plotted against normal probability scores. Linear correlation coefficients were computed for the normal probability plots. A two-tailed paired t-test was done to test for significance at a confidence level of $P<0.05$. A 95% confidence interval for the difference in means was calculated for samples in Category I. For those in Categories II and III, a paired t-test for a difference of means was used to test for significance at a value of $P<0.05$. To evaluate entrainment, a t-test for the difference in means was used to test the differences between the number of peaks on each of the pairs of strip charts and a 95% confidence interval was calculated.

To adjust for the number of t-tests used in this study, the Bonferroni correction was applied. For a difference to be significant at $P<0.05$, a critical value of $P<0.01$ was used to allow for significant differences between individual t-tests. Statistical analysis was done on an Apple Macintosh PowerBook 160 (Apple Computer, Cupertino, CA) computer with StatView 1.03 (Abacus Concepts, Berkeley, CA).

Results

A total of 119 teeth were tested in the 32 children enrolled in the study. The number of subjects used in each test, their mean age, and the number of teeth tested by category are summarized in the Table 1. For Category I (19 teeth measured from 9 children), the evidence of approximation of the data to a lin-

Table 1. Subject Data by Treatment Category

Category*	No. of Teeth	Age Range (yr)	Mean Age (yr)	No. of Subjects†
I (Surface)	19	2.0–5.2	3.6	9
II (Extraction)	22	2.0–7.0	4.4	7
III (RCT)	78	1.2–4.3	3.2	25

*Surface = measurement of the labial and lingual surfaces of the tooth, Extraction = measurement before and after extraction of the tooth, RCT = root canal treatment (pulp extirpation and obturation). †Some subjects were tested in more than one category.

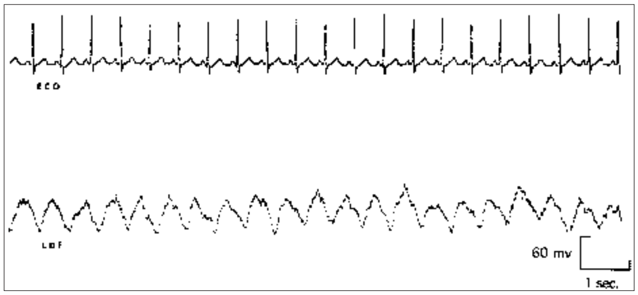

Fig 1. Strip-chart recording of ECG (top) and blood flow pulses (bottom) in the dental pulp of a primary incisor. Peaks of the electrocardiogram R waves and the regular signal fluctuations of the flowmeter (pulsatile blood flow) are time-linked. ECG = electrocardiograph, LDF = laser Doppler flowmeter, mv = millivolts.

ear model (lingual, r=0.985; labial, r=0.989) indicated that the data were normally distributed. Blood flow values measured from the lingual tooth surface (1.70±0.82 mV) were not significantly different from those from the labial surface (1.43 ±0.58 mV; P=0.366; 95% confidence interval=0.263±1.939 mV). For the sample of 22 teeth measured from seven children in Category II, a paired Student's t-test for differences of means showed that blood flow values obtained before extraction (1.636±0.788 mV) were significantly different from values obtained after extraction (0.045±0.074 mV; $P<0.05$). For the 78 teeth measured from 25 children in Category III, a paired Student's t test for difference of means indicated that blood flow values obtained before pulpectomy (1.782±0.847 mV) were significantly different from values obtained after pulpectomy and obturation (0.106±0.084 mV; $P<0.05$).

Fig 1 illustrates the matching of the ECG signal and flowmeter output of pulsatile blood flow in the dental pulp. Statistical results for lack of entrainment were not significant (P=0.419; 95% confidence interval=0.37±0.653 mV). Consequently, there was no difference in the 1:1 matching between the pulse rate recorded by the ECG (mean peak, 25.59±4.14 mV) and that by the flowmeter (mean peak, 25.56±4.16 mV).

In a blind evaluation of randomly selected analog records, two independent observers were able to identify 100% of the records from teeth with vital pulps and 100% of the records from teeth with nonvital (pulp extirpation or extracted) pulps based upon written instructions.

Discussion

All neural stimulation pulp vitality tests rely upon the patient to perceive pain and relay that information to the dentist. Any test based on the subjective appreciation and description of repeated pain stimuli is prone to the full range of pain-based motivational-affective interpretations[13] or refusal of assent. Our study shows that laser Doppler flowmetry is a noninvasive, objective, painless method for the measurement of intrapulpal blood flow in primary incisors.

In this study, we measured the lingual surface of the primary incisors because of the small surface area available on the labial surface when dental caries are extensive. Although previous studies[6, 10–12, 14] of permanent teeth have used the labial surface, we found no statistically significant difference between values recorded at the labial or lingual sites of the primary incisors.

We found that the laser Doppler flowmeter could reliably measure both the presence and absence of pulpal blood flow. When we measured the same teeth under two conditions (with and without blood flow), we found statistically significant differences between blood flow before and after either extraction or pulp extir-pation and obturation.

When the analog record of the flowmeter was compared with that of an ECG, linkage of the analog record of the ECG signal to pulsatile variations in the flow- meter record was verified. This demonstrated the instrument's ability to measure changes in blood flow that were entrained in a 1:1 ratio with the ECG (Fig 1). The ECG is the most common measure of cardia electric activity and has been used in other studies.[6, 7] We have shown that the laser Doppler flowmeter is reliable and may be used without ECG verification.

Finally, a comparison of tracings from the flowmeter for incisors with and without vital pulps verified that differences between the two conditions were visually recognizable. Based on the evidence of this study, therefore, the laser Doppler flowmeter provides a valid means of measuring blood flow in primary incisors.

Measurement of the vascular integrity of traumatized primary teeth is superior to the secondary evidence of neural conduction and radiographic signs. This and similar laser Doppler flowmeters may allow clinicians to manage care rather than continue to rely on their observation of the late signs of pulpal necrosis.

Conclusion

Although several methods of testing pulpal vitality exist, the laser Doppler flowmeter is the only one that is objective, noninvasive, nonpainful, direct, and acceptable to young children. This investigation shows that it also has the characteristics of reliability, reproducibility, standardization, and ease of use. It has immediate clinical applications in the assessment of the vascular status of the pulp of primary teeth.

This paper was prepared with the assistance of Editorial Services, The Hospital for Sick Children, Toronto, Ontario, Canada.This research was done in partial fulfillment of the requirements for Dr. Fratkin's MSc degree.

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