# Evaluation of Pulpal Blood Flow Changes in Primary Molars with Physiological Root Resorption by Laser Doppler Flowmetry and Pulse Oximetry

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***Aim:*** *The aim of this study was to undertake a comprehensive quantitative investigation of pulpal blood flow (PBF) changes in human non-carious primary molar teeth with variable degrees of root resorption by Laser Doppler Flowmetry (LDF) and Pulse Oximetry (PO) methods.* ***Materials and Methods:*** *Data was collected from clinically and radiographically healthy 86 mandibular primary molars which have different physiological root resorption levels (PRRLs). PRRLs for each of the teeth were assessed using periapical radiographs and teeth were subdivided into three groups.* ***Results:*** *The LDF values demonstrated a significant difference (p = 0.0001) between all groups although PO did not demonstrate any difference (p = 0.109). Statistical analysis of LDF values demonstrated significant differences between Groups A and C (p = 0.0001) and Groups B and C (p = 0.008). Furthermore, positive correlations were determined between LDF values and PRRL groups (p = 0.0001) and patients' ages (p = 0.0001).* ***Conclusions:*** *In our study, it was observed that the PBF values of human primary molars measured by LDF tended to increase with the progress of physiological root resorption and age. LDF was found to be a more effective method than PO to assess the pulpal vascularity changes of human primary molars.*

***Keywords:*** *Laser Doppler Flowmetry, Pulse Oximetry, Pulpal Blood Flow, Primary Molars, Physiological Root Resorption*

J Clin Pediatr Dent 36(2): 139–144, 2011

## INTRODUCTION

The primary molar teeth in particular should be retained until they exfoliate naturally to avoid loss of space and crowding of the permanent dentition. Although the basic aims of dental treatment in children are similar to those for adolescent patients, due to the morphological and physiological differences between primary and permanent teeth, treatment alternatives, techniques, and medicaments vary. The lack of correlation between clinical signs and symptoms and the histopathology dental pulp status of primary teeth makes it difficult to determine the vitality of primary teeth with pulpal pathosis.[1,2] The vitality assessment is a critical diagnostic procedure in the diagnosis of pulp disease. But the diagnosis of pulp disease is very difficult in children, especially in the anxious or uncooperative ones, because they are usually unable to give an accurate account of their symptoms. However, the most widely used traditional pulp vitality test methods such as electric pulp testers (EPT) and thermal stimuli are of little clinical value in children because they determine only the pulp sensitivity to the stimuli used but give no direct indication of blood flow within the pulp.[3-8] Because of this, a thorough understanding of pulpal vascularity, healing capacity, and defence potential especially during the various stages of root resorption is a prerequisite for selecting the appropriate treatment for successful pulpal therapy of primary molars.[2] However, information concerning the vascular changes, pulpal healing and defence capacity of primary molars during the ageing period beginning with physiological root resorption (PRR) and ending with exfoliation is very limited.

Pulse Oximetry (PO) and Laser Doppler Flowmetry (LDF) are non-invasive methods for assessing blood flow in microvascular systems which have been introduced as new methods to evaluate the pulpal blood flow (PBF) of human teeth.

PO is a relatively recent advancement in non-invasive monitoring of oxygen saturation ($SaO_2$) of the blood and pulsatile of the patient. It is effectively and routinely used in medical applications through the use of finger, toe, ear, and foot probes. Its wide acceptance in the medical field results from its ease of application and its ability to provide vital

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information about the patient's status.[5-7] The principles of PO are based on a modification of Beer's law and the absorbance characteristics of haemoglobin in the red and infrared range. The PO probe consists of a photo-detector and two Light Emitting Diodes (LED). One of the LED transmits red light (640 nm), the other transmits infrared light (960 nm) to the vascular tissue. Oxygenated and deoxygenated haemoglobin absorbs different amounts of red and infrared light. The pulsate change in the blood volume causes periodic changes in the amount of red and infrared light absorbed by the vascular tissue before reaching the photo-detector, and PO uses this information to calculate the pulsatile and $SaO_2$. [5-7]

LDF is a non-invasive electro-optical technique which has been shown to have potential as a method of assessing the vitality of teeth by detecting the presence or absence of a PBF.[8,9] The LDF technique utilizes a beam of infrared (780–820 nm) or near infrared (632.8 nm) light that is directed to the tissue by optical fibres within a specially designed probe. Monochromatic laser light is transmitted through the crown of the tooth to the dental pulp via the probe and it is scattered by moving red blood cells and stationary tissue cells. Photons which are reflected from the moving red blood cells are scattered and frequency shifted according to the Doppler principle. Photons that interact with stationary tissue cells are scattered but not Doppler shifted. The proportion of shifted to unshifted light within the reflected light gives a semi-quantitative measurement of blood flow through the tissue and is recorded as a voltage output from the LDF.[8–11] The measured voltage was linearly related to the PBF and expressed in arbitrary perfusion units (1 PU = 10 mV) in accordance with general consensus (European Laser Doppler Users' Groups, 1992).[8-14]

Therefore, the aim of this study was (i) to undertake a comprehensive quantitative investigation of PBF changes in non-carious human primary molar teeth with variable degrees of root resorption by LDF and PO methods and (ii) to compare the efficacy of these two methods.

## MATERIAL AND METHODS

The study sample comprised of 41 patients (range 7–11 years, mean age 9.6 ± 1.2 years, 23 female, 18 male) attending the Department of Pedodontics, Süleyman Demirel University, Faculty of Dentistry (Fig. 1).

The participants had no history of systemic vascular or cardiovascular disease or any evidence of hypertension, and none of them were taking any medication. The research ethical committee of S. Demirel University, Faculty of Medicine approved of the study (09.03.2006-02/17). The experimental purpose and methodology of the study were explained to the patients or their parents/careers and informed consent was obtained.

A complete history was taken and clinical and radiographic examination of patients was carried out by the same examiner in accordance with normal clinical practice. Inclusion criteria dictated that tooth samples were (i) intact teeth with no caries, restorations or fractures, (ii) had no enamel defect or discolouration (iii) and had a permanent successor. The submerged teeth and the teeth with abrasion or erosion were excluded from the study. Data were collected from 86 clinically and radiographically healthy mandibular primary molar teeth (31 first, 55 second molar) which had different physiological root resorption levels (PRRLs).

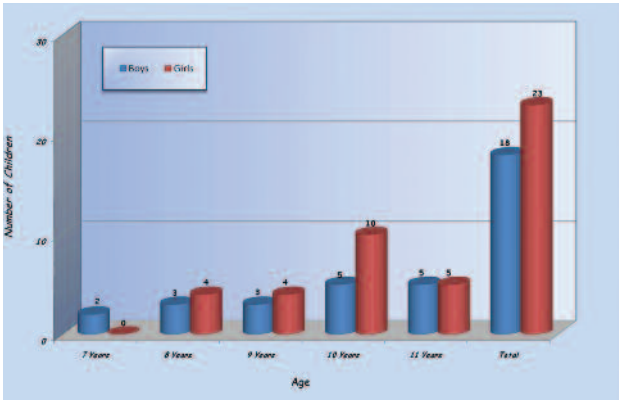


**Figure 1.** Distribution of children according to age and gender.

PRRLs for each of the teeth were assessed using periapical radiographs taken under standardized conditions using a Dens-O-Mat (Gendex, Dentsply, Italy) and KODAK ultra speed film (Speed Group D) with similar exposure times and a fixed film–object–tube distance. The distance between the furcation and the deepest point of root resorption of the primary molars was measured by one investigator using a pair of compasses. For each molar, the most resorbed root was selected for this purpose. PRRL was determined according to standardized values published by Kramer and Ireland.[15]

After determining the PRRL by the method described, teeth were subdivided into three groups: (i) Group A, teeth with less than one-third root resorption (n = 30 teeth), (ii) Group B, teeth with one-third to two-thirds root resorption (n = 27 teeth), and (iii) Group C, teeth with more than two-thirds root resorption (n = 29 teeth) (Table 1). Examples from Groups A, B, and C are shown in Figure 2a, b, and c.

All measurements were performed in a temperature controlled room (24 ± 1 ºC) using the same unit and keeping the same position. The patients rested for 10 min in the unit before the measurements were taken and they were warned

**Table 1.** The distribution of 86 teeth according to PRRL groups and age.

| | | *Age (n= 86 teeth)* | | | | | *Total* |
|---|---|---|---|---|---|---|---|
| | | *7 Years* | *8 Years* | *9 Years* | *10 Years* | *11 Years* | |
| *PRRL GROUPS* | *Group A* | 6 | 16 | 8 | 0 | 0 | 30 |
| | *Group B* | 0 | 2 | 7 | 18 | 0 | 27 |
| | *Group C* | 0 | 0 | 0 | 9 | 20 | 29 |
| *Total* | | 6 | 18 | 15 | 27 | 20 | 86 |

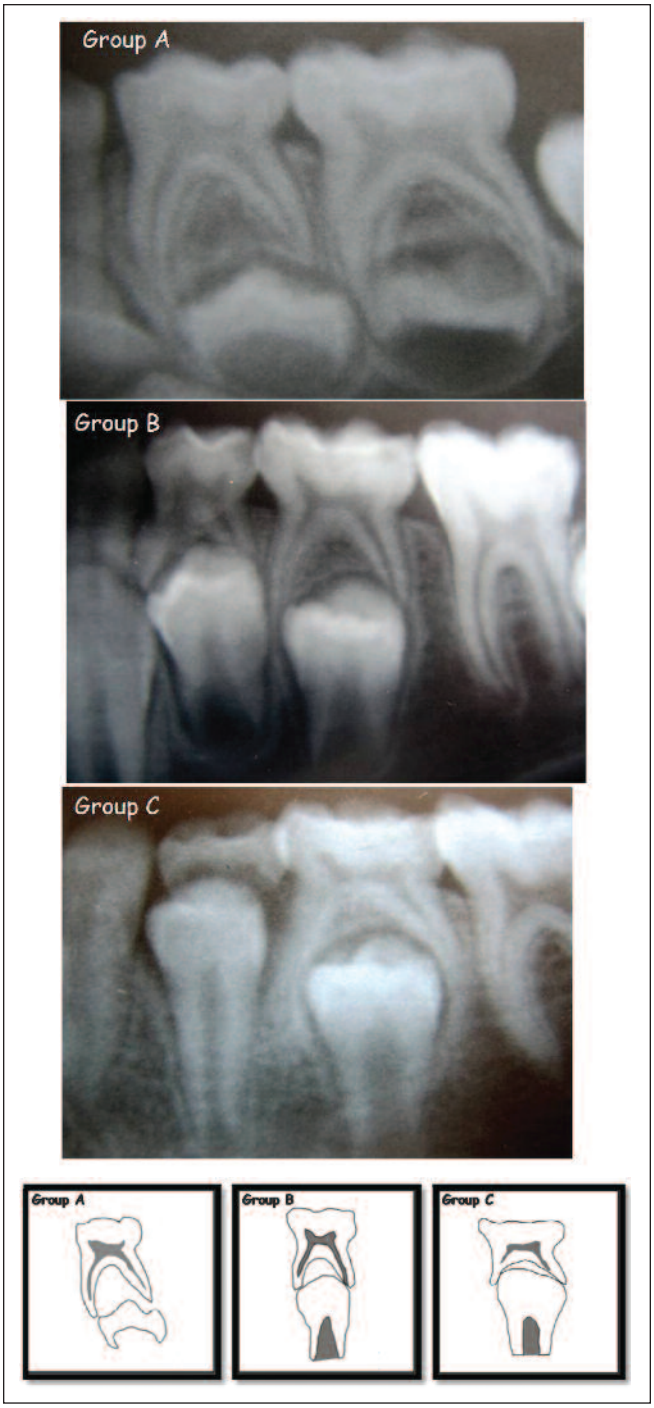


**Figure 2a, b, c.** Examples for Group A, B and C.

to abstain from hot or cold foods and beverages for at least two hours before attending.

**The PO Device:** A commercially available Life Scope I, Multiparameter Bedside Monitor (Model BSM-2301K, Nihon Kohden Corp., Tokyo, JAPAN) and a modified infant probe were used to record $SaO_2$ levels. Special probe holders were designed, taking into consideration the morphology of the mandibular primary molars, to hold the modified probe on the tooth. Stainless steel clips and rubber dam clamps were used as the base for the holders. The tapes enclosing the LEDs and photo-detector of the infant probe were removed and attached to the holder in parallel to each other (Fig. 3).

**The PO Measurement Procedures:** The probe was positioned on the cervical region of the crown of the tooth

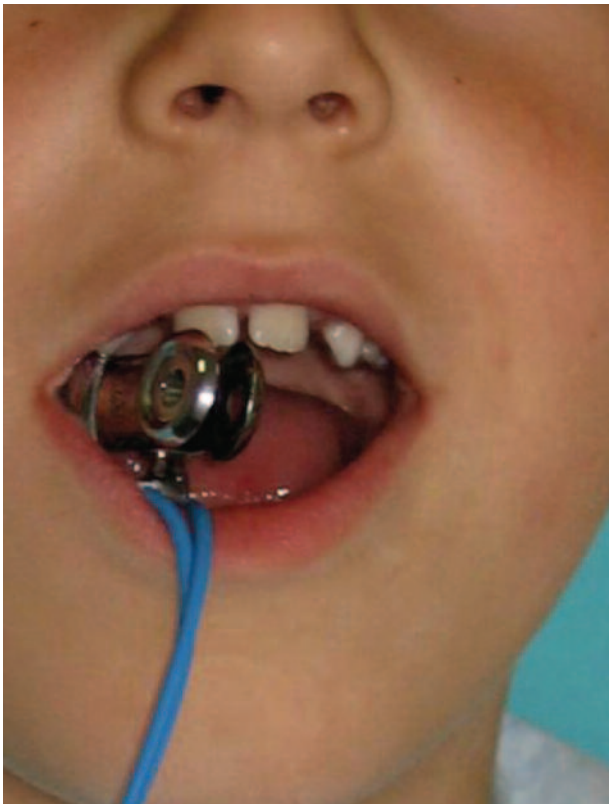

**Figure 3.** The placement the modified infant probe with probe holder on the tooth and the measurement procedure.

using a probe holder so that light would travel from the facial to the lingual/palatal side through the middle of the crown. PO values were recorded after 45 s of monitoring for each of the teeth. If there was no response at the end of the measurement period the PO values of the tooth were recorded as negative (Fig. 3).

**The LDF Device:** The PBF of the teeth was measured by a commercially available LDF device (BLF21A, Transonic Systems Inc. Ithaca, NY, USA; wavelength 780 nm) and a custom made dental probe (external diameter 1.5 mm; two 0.2 mm diameter fibres; centres 0.5 mm apart) in this study.

**The LDF Measurement Procedure:** Silicon-impression-based personal splints were prepared to ensure accurate and reproducible positioning of the probe on the tooth for each of the participants. On the labial side of the splints, holes 2 mm above the gingival margins were drilled to insert and fix the probe. The probe was held perpendicular to the surface of the crown 2 mm from the gingival margin by using these splints.

Evaluation took 45 s for each tooth and data were collected by a PC connected to the LDF device while maintaining a real time display on the monitor. The 20 s of the

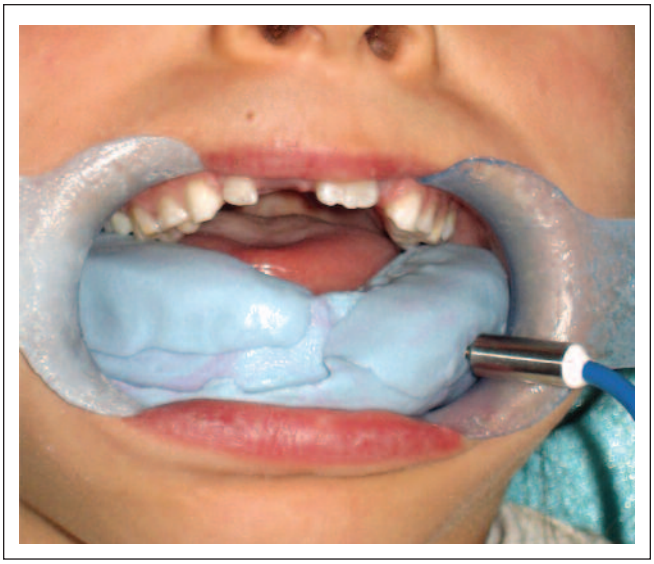

**Figure 4.** Silicon-impression-based personal splints were used to ensure accurate and reproducible positioning of the probe on the tooth.

data which were the optimum part of the measurement were selected for the study by a special software package (Windaq ver. 2.36, DATAQ Instruments Inc., Akron, OH,USA) and the average PBF of the teeth was calculated in perfusion units (PU) by the same software (Fig. 4).

**The EPT Measurement Procedures:** A conventional electrical pulp tester (Pulptester, Model PT-20, Parkell Inc., Edgewood, NY, USA) was used for EPT and the response was recorded as positive if the teeth tested showed any response on the aforementioned scale or negative if there was no response.

**Other Measurements:** The following measurements were performed to examine the effects on the values obtained from the teeth by PO and LDF.

- The systemic $SaO_2$ level and pulsatile of the patient were measured by the PO device from the index finger using a finger probe.
- Systolic and diastolic arterial blood pressures were also measured and recorded.

Statistical analysis (paired t test, Kruskal-Wallis, Mann Whitney U, Pearson's correlation) were performed using SPSS (Ver. 13.0, SPSS Inc., Chicago, IL, USA) at $p < 0.05$ significance level. Furthermore, the sensitivity and specificity were calculated.

## RESULTS

The mean LDF value of first primary molars was 11.87 ± 2.4 PU and that of second primary molars was 12.11 ± 2.8 PU. The mean PO value of first primary molars was 84.71 ± 4.4 and that of second primary molars was 83.58 ± 5.1. The average PO and LDF values obtained from mandibular primary molars and PRRL groups have been summarized in Tables 2 and 3. Neither the LDF ($p = 0.784$) nor the PO values ($p = 0.372$) showed any significant difference between first and second primary molars ($p > 0.05$).

The LDF values demonstrated statistically significant differences ($p = 0.0001$) between all groups but PO did not demonstrate any difference ($p = 0.109$). Statistical analysis of LDF values demonstrated a significant difference between Groups A and C ($p = 0.0001$) and Groups B and C ($p = 0.008$), but no significant difference between Groups A and B ($p = 0.084$).

Furthermore, significant positive correlations were determined between LDF values and PRRL groups ($r = 0.50$, $p = 0.0001$) and patient age ($r = 0.39$, $p = 0.0001$) (Figs. 5 and 6). However, PO did not show any statistically significant correlation with PRRL ($p = 0.087$) and age ($p = 0.120$).

Sixteen false negative responses were received by EPT

**Table 2.** The distribution of PBF values obtained from molar teeth by LDF and PO.

| | *First Primary Molars* | | | | *Second Primary Molars* | | | | *Total Teeth* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | |
| ***LDF (PU)*** | 31 | 7.38 | 17.77 | 11.87±2.45 | 55 | 6.97 | 18.11 | 12.11±2.79 | 86 | 6.97 | 18.11 | 12.02±2.66 | p=0.784 |
| ***PO (%)*** | 31 | 75 | 91 | 84.71±4.44 | 55 | 75 | 92 | 83.58±5.09 | 86 | 75 | 92 | 83.98±4.87 | p=0,372 |

**Table 3.** The distribution of PBF values obtained from PRRL groups by LDF and PO

| | *Group A* | | | | *Group B* | | | | *Group C* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | ***n*** | ***Min.*** | ***Max.*** | ***Mean±SD*** | |
| ***LDF (PU)*** | 30 | 7.28 | 15.11 | 10.583±2.26 | 27 | 6.97 | 17.29 | 11.736±2.33 | 29 | 9.10 | 18.11 | 13.772±2.39 | **p=0.0001** |
| ***PO (%)*** | 30 | 76 | 92 | 84.633±4.78 | 27 | 77 | 91 | 84.925±4.30 | 29 | 75 | 92 | 82.448±5.23 | p=0,109 |

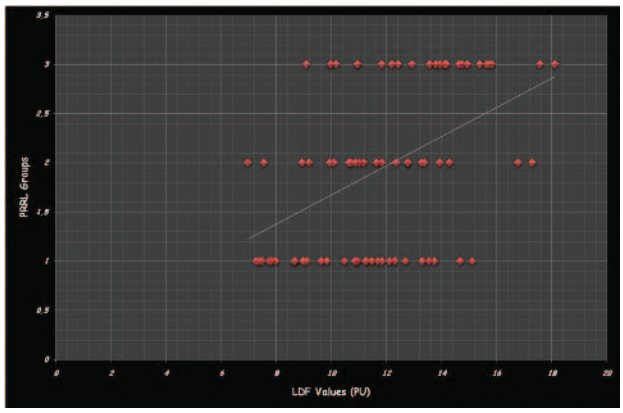


**Figure 5.** Significant positive correlation was determined between LDF values and PRRL groups (r=0.50, p=0.0001).

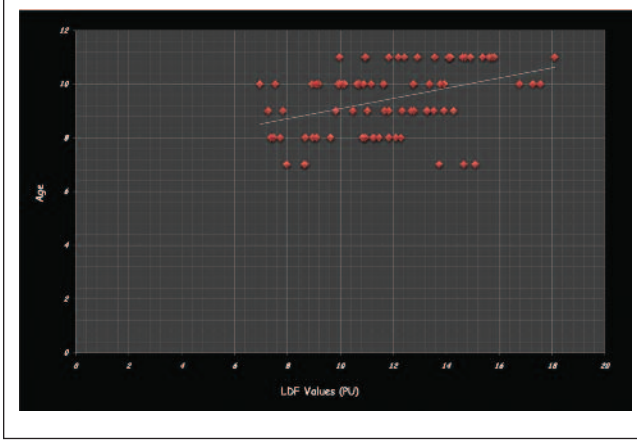


**Figure 6.** The positive correlation determined between LDF values and patients age (r=0.39, p=0.0001) was statistically significant.

from 86 primary molars and the observed specificity of EPT was 0.83.

Neither the LDF nor the PO values showed any significant relationship with regard to gender, pulse rate, systemic blood pressure, and systemic $SaO_2$ levels ($p > 0.05$).

## DISCUSSION

The tooth pulp is a highly vascular tissue, comprising precapillary arterioles, capillaries, post-capillary venules, muscular venules, and lymphatic's, which enter the tooth via the apical foramina and ascend towards the coronal region.[16] Some authors report that the structure of primary tooth pulp is similar to that of young permanent tooth pulp.[2, 17-19] Others claim that human primary tooth pulp is frequently more vascular tissue than the permanent tooth pulp.[20,21] But these statements have not been scientifically proven and there appears to be little quantitative data in the literature relating to human pulpal vascularity, particularly for the primary tooth pulp.[16,20,21]

Findings from previous descriptive studies of pulpal vascularity changes of primary teeth during PRR are conflicting. Sari *et al* [18] examined 14 extracted primary canines at different stages of root resorption. They reported normal pulpal vascularity in resorbed samples. Rapp[22] investigated the vascular pathways of human primary teeth pulps and reported that with advanced root resorption, the number of fine arteriole-like structures arising within the coronal pulp was decreased and capillaries and smaller venous structures were not detected. In contrast, a more recent study of 19 primary teeth with various stages of PRR identified hyperaemia and dilated blood vessels in a small number of teeth.[23] Monteiro *et al* [24] reported that increased vascularity was evident in some teeth with advanced root resorption.

Primary teeth pulps have one very distinct feature which sets them apart from the pulp of permanent teeth. Primary teeth undergo PRR leading to exfoliation.[24] Due to its complexity, the mechanism of PRR is not yet fully understood. The changes in pulpal vascularity, healing, and defence capacity during the ageing period beginning with PRR and ending with exfoliation are controversial. Therefore, the main aim of this study was to determine whether any changes occur in the PBF of human primary molars in association with PRR by LDF and PO methods.

In our study, it was determined that the PBF of primary molars is increased with age and PRRL. This is considered to be associated with morphological and histological changes of the pulp by age and PRRL. These findings concur with those of Bolan and Rocha and Monteiro *et al* [24] who reported hyperaemia and dilated blood vessels in their qualitative study of resorbing primary teeth. This may reflect the higher metabolic demands of odontoclastic cells during active phases of root resorption. The presence of a good blood supply may have considerable biological importance in provision of nutrients and removal of metabolic waste products.[24] The increase with age and PRRL, as previous investigators have suggested, may be a reflex of the resorption process itself, as a consequence of the widening of the apical region.[18,24]

Unfortunately, there is only one previous quantitative study of vascularity changes in human primary teeth carried out by the LDF method with which our findings may be compared.

Komatsu *et al* [25] examined the age-related changes in the PBF of 21 maxillary primary central incisors in 12 children (4–7 years old; mean: 5.5 years) and reported that the PBF in human primary teeth decreases with age. They considered that the decrease in PBF is closely related to the morphological changes of the blood vessels in the pulp by PRR. The incompatibility between our findings and theirs may be caused by the differences in the age of the children and tooth type of the primary teeth selected for the study. The differences in the number of children and teeth evaluated in these studies may be another cause of this disagreement.

To the best of our knowledge, no study to date has evaluated vascularity changes of human primary teeth with age and PRRL by using the PO method. Only Goho[5] showed in a pilot study that pulpal circulation and oxygen saturation of maxillary primary incisors can be detected by the PO

method, but did not evaluate the vascular changes of primary teeth during PRR and age.[5]

The ideal technique for the evaluation of dental pulp status must be non-invasive, objective, painless, reliable, reproducible, and standardized.[26] In view of our results, using LDF as a vitality test method, appeared that we could diagnose pulpal vascularity changes more accurately than with PO and EPT. The LDF method leads to less pain and discomfort for the patient, less cost, and earlier treatment. However, despite its advantages, LDF still has a number of specifically technical limitations.[8,27,28] These include motion artefact noise, multiple Doppler shifting, variations in instrument and probe specifications, lack of quantitative units and knowledge of depth of measurements, lack of knowledge of normal PBF values of healthy teeth, environmental effects on the measurements, and the high cost of the instrument.

## CONCLUSION

PBF values of human primary molars measured by LDF tended to increase with the progress of PRR and age. LDF was found to be a more effective method than PO and EPT for assessing the pulpal vascularity changes of human primary molars in paediatric patients where patient cooperation and incomplete pulp innervations reduces the effectiveness and reliability of conventional vitality test methods. However, to the best of our knowledge, this is the first study to examine the pulpal vascularity changes of human primary molars. Therefore, further research is indicated to improve the LDF method and device to allow them to become a valuable clinical diagnostic tool in dental practice.

## ACKNOWLEDGMENTS

This study was supported by the scientific research grants given by Süleyman Demirel University (SDUBAP, 2004-93 and 1212-D-05).

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