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The use of pulse oximetry in evaluation of pulp vitality in immature permanent teeth

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Abstract – *Background and aim*: The current methods of pulp vitality assessment, either electric or thermal, are of limited use in children. Recently, traumatized and immature teeth may not respond to such methods and because such methods require subjective responses, it may not provide accurate results particularly in children. Pulse oximetry, an atraumatic approach, is used to measure oxygen saturation in vascular system. The aim of this study was to investigate the use of pulse oximetry to evaluate pulp vitality status in immature permanent teeth. *Methods and materials*: The study was conducted on 329 maxillary central and lateral incisors in children. The negative control group consisted of 10 root filled teeth. Systemic oxygen saturation was first measured on the thumb of the individual using a custom-made sensor. Oxygen saturation values of the teeth were then evaluated. The correlation between oxygen saturation measurement obtained from finger and tooth, and the correlation between oxygen saturation values and stage of root development were analyzed. A further comparison was made between the teeth with open and closed apex. *Results*: Mean oxygen values recorded in the patient's finger were 97.17%, and mean oxygen values in the maxillary central and lateral incisors were 86.77% and 83/92%, respectively. There was no significant correlation between blood oxygen levels in the finger and in the teeth. ($P > 0.05$) There was a significant negative correlation between the stage of root development and the blood oxygen levels in the patients' teeth. ($P < 0.05$) Mean oxygen values in the teeth with open apex were significantly higher than the teeth with closed apex. ($P < 0.001$). *Conclusion*: Vital teeth provided consistent oxygen saturation readings, and non-vital teeth recorded no oxygen saturation values. During tooth development, the oxygen saturation values decreased. These findings confirm that the pulse oximetry is capable of detecting the pulpal blood flow and oxygen saturation.

The assessment of pulp vitality is a crucial diagnostic procedure in the treatment of teeth with caries or trauma. Clinical aids such as radiographs, mobility, percussion, palpation, trans illumination, and evaluation of the discoloration of a tooth crown are currently used to distinguish a normal pulp from a necrotic one. The thermal and electrical tests (sensibility tests) have also been used to register sensitivity of pulpal nerves (1, 2). However, a major shortcoming of such tests is that they do not evaluate pulp vitality directly, but through measuring the neural response. Consequently, the tooth that temporarily or permanently has lost its sensory function (e.g. damaged by trauma) may be non-responsive to such tests. In such conditions, the tooth may have an intact vasculature (3–5). Moreover, the nervous tissue, being highly resistant to inflammation, may remain reactive long after the surrounding tissues have degenerated. Therefore, the thermal and electrical tests may give false-positive responses when the pulp vasculature is damaged. Furthermore, false-negative responses are possible in primary and young permanent teeth due to immature innervations (6–8). Variations in sensitivity threshold of the patient, factors such as fear, anxiety, and the anticipation of pain can lead to incorrect interpretation of the data (9).

Recent attempts to develop a method for determination of pulpal circulation have involved the use of laser doppler flowmetry, dual-wavelength spectrophotometry, and pulse oximetry (10–14). The pulse oximetry approach is a non-invasive method to show blood oxygen saturation level in blood circulations. It is widely used in medical practice during the administration of intravenous anesthesia (1). Pulse oximetry uses a probe containing two light-emitting diodes (LEDs): one transmits red light energy (660 nm) and the other transmits infrared light energy (940 nm). Oxygenated and deoxygenated hemoglobin absorb different amounts of red and infrared lights. At 660 nm, oxygenated hemoglobin absorbs less light than deoxygenated hemoglobin, while at 940 nm of infrared light, the opposite can be observed. Both lights are received by a photodetector diode connected to a signal-processing unit. The pulsatile change in the blood volume causes periodic changes in the amount of red and infrared light absorbed by the vascular bed before reaching the detector. The relationship between the pulsatile change in the absorption of red light and infrared light is assessed by the oximeter to show the saturation of arterial blood. It uses this information together with known absorption curves for oxygenated and deoxygenated hemoglobin, to determine the oxygen saturation levels (15–17).

In a normal person, 100 ml of blood contains 15 g hemoglobin, and each gram transports 1.34 ml of oxygen, as a result when there is 20 ml oxygen in 100 ml of blood, oxygen saturation is 100% (18).

With monitoring the changes in the oxygen saturation level of pulpal blood flow, the pulse oximetry could be able to detect pulpal inflammation or partial pulp necrosis in teeth, which are still responsive to other current tests (19).

The aim of this investigation was to evaluate the pulse oximetry potential in the evaluation of the pulp vitality in immature permanent teeth.

Materials and methods

The current clinical study was carried out on 187 teeth (both central and lateral incisors), with open apex and 132 teeth (both central and lateral incisors) with closed apex, belonging to 123 children, aged 68–166 months. After complete dental examination, patients and/or parents were asked about any history of trauma to face, mouth, teeth, or chin, and finally, radiographs (panoramics) were screened for any signs of dental injury. The inclusion criteria were as follows: (i) teeth free of caries, fracture, or color change (teeth with clinically intact crown) (ii) no history of trauma to face, mouth, or teeth, and (iii) patients who needed to have panoramic radiographs for other reasons. (Panoramic views were obtained on the same day or following days of their attendance).

Exclusion criteria were as follows: (i) teeth with pain symptoms, (ii) history of dental trauma, (iii) teeth with caries, color change, or advanced periodontal disease, (iv) teeth with swelling or increased mobility, and (v) teeth with tenderness to apical palpation or vertical and horizontal percussion.

ALBORZ B5 (Masimo SET/SAADAT, IRAN) pulse oximeter and FMT-RAF-MSM-L (Metko Ltd, Istanbul, Turkey) sensor were used for the evaluation of the pulp vitality. A custom-made sensor holder was designed to ensure accurate placement and adaptation of the sensor on the teeth (Fig. 1). A custom-made sensor was designed and built out of an existing pulse oximeter through a replacement of the arms with a simple cloth clips adjusted in form and size to the teeth surfaces with pieces of PVC material. Sensor parts were then mounted in each wing of the clips. A disposable cover served to enable its multiple uses.

To verify the correct function of the custom-made sensor, 15 patients were selected and subjected to the SO2 test. Oxygen saturation values were recorded on patient's fingers with the original as well as custom-made sensors and on patient's fingers using a custom-made sensor with and without cover.

Systemic oxygen saturation values were measured firstly on the patient's thumb with custom-made sensor (Fig. 2). The second measurements were then taken from the teeth of the same patients with the same sensor. The testing area was isolated using a cotton roll. The patients were instructed to avoid any sudden movement of the head during the test reading. The operating light and all intense fluorescent ambient lights were shut down during the measurements to prevent any interferences with capturing the signal. The sensor was positioned on the patient's tooth in such a way that the emitting diode was on the buccal surface and the receiving diode on the palatal surface (Fig. 3).

Oxygen saturation values were recorded after 15 s of monitoring each tooth. In 20 patients, teeth oxygen saturation was obtained in two consecutive measurements with 10 min intervals for evaluating data reproducibility. Panoramic radiographs of patients were evaluated to determine whether the apex was closed or open.

The stage of the root development was recorded based on the model presented in Fig. 4 derived from earlier studies on root formation stages (20, 21).

The oxygen saturation values were measured in 10 non-vital (root filled) teeth as negative controls.

Interitem reliability test was carried out for the following comparisons. (i) A comparison between oxygen saturation values obtained from the patient's finger using a custom-made sensor with and without its cover. (ii) A comparison between oxygen saturation values obtained from the patient's finger with the original pulse oximeter sensor and the custom-made sensor. (iii) A comparison between oxygen saturation values obtained from the teeth in two measurements with 10-minute intervals. Pearson statistical test was carried out to determine correlation between tooth and finger readings. Spearman rank correlation test was carried out to

Fig. 1. Custom-made sensor holder.

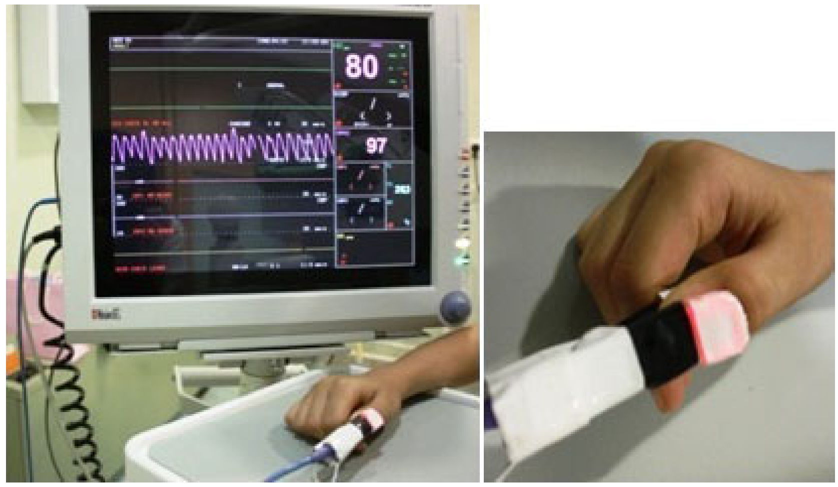

Fig. 2. Sensor holder on patient's thumb finger.

Fig. 3. Sensor holder on patient's tooth.

determine correlation between tooth reading and stage of root development. Finally, *t*-test statistical analysis was carried out for comparing the mean oxygen saturation value in teeth with closed apex and with open apex.

Results

Interitem reliability tests indicated reliability between all the comparisons, as there were no significant differences between readings obtained using custom-made sensor with or without cover, between the readings obtained from the original pulse oximetry sensor and the pulse oximetry with custom-made sensor, and between the readings obtained in 10-minute intervals. Thus, there were no interferences of the above variables in the results of the present study.

All the 10 root filled teeth gave oxygen saturation values of 0% suggesting no vascularity. The mean oxygen saturation value of the patient's finger was 97.17% (SD = 1.291) which is in the normal range (17, 18).

The mean oxygen saturation value of the teeth with an open apex was 86.71% (SD = 2/052) in left central, 86.83% (SD = 2/293) for right central, 84.50% (SD = 1.518) in left lateral, and 83.35% (SD = 1.578) for right lateral.

The mean oxygen saturation value of the teeth with a closed apex was 84.61% (SD = 2.170) in left central, 85% (SD = 2.062) in right central, 83.14% (SD = 1.432) in left lateral, and 81.82% (SD = 1.565) for right lateral.

There was no correlation between blood oxygen saturation in the finger and in the teeth (Table 1).

Comparing the data using a *t*-test revealed the mean oxygen saturation value in teeth with a closed apex was significantly lower than teeth with an open apex ($P < 0.001$).

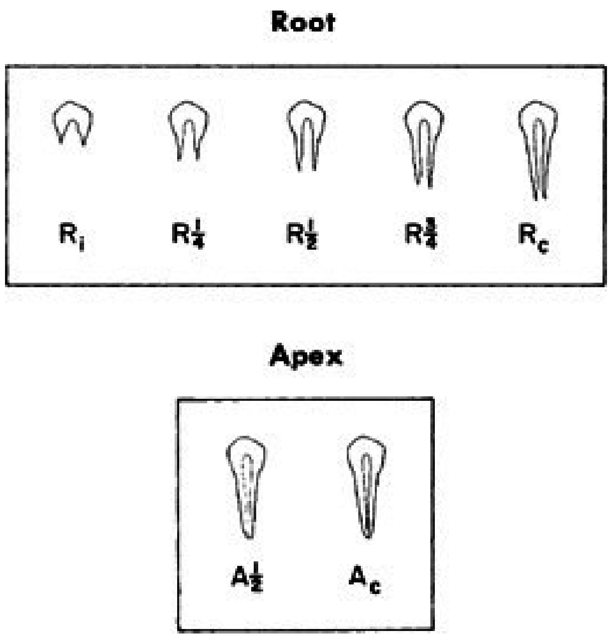

Fig. 4. Applied model for staging root development.

Table 1. Pearson correlation for the readings of blood oxygen saturation and finger

	Finger and left central	Finger and right central	Finger and left lateral	Finger and right lateral
Pearson's correlation	0.052	−0.019	0.080	−0.135
P-value	0.617	0.853	0.505	0.273
n	95	95	71	68

There was a significant negative correlation between the stage of the root development and blood oxygen level in the teeth (Table 2). The higher the stage of the root development, the lower the blood oxygen.

Discussion

The pulse oximetry was effective in assessing oxygen saturation because it confirmed the avascularity of the root filled tooth. Mean oxygen saturation readings in the teeth with a closed apex was 84.8 for central incisors and 82.48% for lateral incisors, while in Gopikrishna et al. (22) study, the mean oxygen saturation readings were 79.31% for central incisors and 79.61% for lateral incisors. The difference observed in the results of the present study with those of the Gopikrishna et al. can be attributable to the age differenced of the participants in the two studies, in that the participants in our study were between the ages 9 and 14 and in Gopishrishna et al. study between 15 and 40. The higher oxygen saturation values can be attributed to a greater vascularization in children (6).

The results of the present study are also different from those reported by Calil et al. (9) in that the mean oxygen saturation readings in central incisors with a closed apex recorded after 5 s were 91.29. Thus, the differences in the results of the present study with those of Calil et al. could be explained by the different timing of the monitoring.

According to the results of the study, the pulse oximetry was also effective in evaluating oxygen saturation values in relation to the stages of the root development. The mean oxygen saturation value in teeth with close apex was lower than those with open apex. Also, there was a significant negative correlation between the stage of the root development and blood oxygen level in the teeth. This could be related to differences between the level of vascularity between the two groups. During root development, apical region diameter decreases, reducing the blood flow (23, 24). This could verify the reliability of the pulse oximetry in detecting tooth vascularization.

The oxygen saturation values obtained from both closed and open apex teeth were lower than those obtained from the patients' fingers. A similar finding was reported by earlier studies (3, 9, 22, 23). Several contributing factors could result in lower readings of the teeth compared to the fingers, including diffraction of infrared light by enamel prisms and dentin (25). Fien et al. (26) suggested that the lower oxygen saturation values for pulpal circulation may also be attributed to the light ray scattering through the gingiva.

The result of this study showed that there was no significant statistical correlation between the values obtained from the teeth and those obtained from the fingers. A similar result was reported by Calil (9) and Goho (23) suggesting that systemic oxygen saturation changes do not affect teeth oxygen saturation, so values obtained from teeth could be reliable in various systemic conditions.

Because pulse oximetry is atraumatic approach, it could be easily used in children who have dental fear and anxiety. This method is best performed when the sensor could be kept stable on the tooth during monitoring. To expand the use of pulse oximeter, it is essential to modify the current shape of the sensor in such a way that while it is fixed, the transmitter and the detector could be parallel. A self-mounted device has a more reliable reading than the hand-held ones. Authors hope such device could be ordered for mass production based on the currently designed and introduced method. We recommend using a pulse oximetry with

Table 2. Spearman rank correlation for the readings of blood oxygen saturation of teeth and stage of root development

	Stage of root development and left central	Stage of root development and right central	Stage of root development and left lateral	Stage of root development and right lateral
Spearman rank correlation)	−0.470	−0.327	−0.501	−0.381
P-value	0.001	0.001	0.001	0.001
n	95	95	71	68

fixed custom-made sensor with parallel transmitter and detector for evaluating the tooth vitality. We also recommend further studies to evaluate pulse oximetry in monitoring oxygen saturation level during inflammatory changes in pulpal tissue.

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