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Assessment of pulp blood flow in primary and permanent teeth using pulse oximetry

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Abstract – Pulse oximetry (PO) is a well-accepted non-invasive method for assessing vascular health, based on oxygen saturation (SaO_2) measurements. The objectives of this study were to design and build a custom-made PO dental sensor holder, to evaluate the effectiveness of PO in determining pulp blood flow in primary and permanent teeth, and to compare the SaO_2 levels obtained in teeth and on the little finger of patients. The PO sensor adapted to the custom-made sensor holder is termed as a device to position and hold the PO sensor. This study evaluated SaO_2 readings obtained in the pulp of 123 teeth of 84 children aged 4–13 years. The teeth were divided into three groups: group I – primary teeth: 23 central incisors and 28 canines; group II – permanent teeth: 25 central incisors and 28 canines; and group III – endodontically treated teeth (control): 12 permanent central incisors and seven primary central incisors. The pulp blood flow and SaO_2 were measured and were compared with readings of the patient's finger. Data were analyzed by paired *t*-tests and Pearson's analysis method. The PO was able to identify all the clinically normal pulps contained in the sample, and all the endodontically treated teeth (controls) showed no response. The mean SaO_2 values were 85.27% in the teeth and 92.85% in the fingers. In conclusion, PO readings were effective in determining pulp blood flow in primary and permanent teeth. However, there was no correlation between the SaO_2 values in the fingers and in the teeth of the patients ($P < 0.05$).

The assessment of pulp vitality is required to assess the state of the pulp and whether any treatment is required. Currently, the tests most commonly used for this purpose are mainly thermal and electric pulp tests (1). However, these methods have limitations in providing an accurate diagnosis, because they subjectively imply vitality through sensory responses from the patient, leading to inconclusive results, especially when used in children (2, 3). Furthermore, sensitivity test*s* are perceived as unpleasant and occasionally painful stimuli, which may cause cooperation problems and require behavior management in the pediatric population (2).

Rapp et al. (4) suggested that primary teeth show less pain sensitivity when compared with permanent teeth resulting from differences in the number and/or innervation of their neural components, such as the Raschkow plexus. Primary teeth are composed of a less dense network of myelinated fibers. In addition, nerve fibers are seldom found in the calcified tissues of primary teeth (4). These typical characteristics of primary teeth can probably explain why these teeth are less sensitive to pulp sensitivity tests.

A major limitation associated with conventional pulp testing methods is that they indirectly monitor pulp vitality by measuring a neural response, not vascular circulation (5, 6). Moreover, pulp vitality is a function of vascular health, which depends on the blood supply. Thus, vascular supply, not innervation, is the most accurate determinant for assessing the status of the pulp (5).

Because of the essential role of pulpal circulation in maintaining tissue health, recent attempts to develop a method for the determination of blood supply in pulpal tissues have involved the use of physiometric tests, such as laser Doppler flowmetry (7–9), dual wavelength spectrophotometry (10), photoplethysmography (11), and pulse oximetry (PO) (2–6, 12–16).

Pulse oximetry is a non-invasive medical monitoring procedure for the determination of blood oxygen saturation (SaO_2) levels and real-time pulse rate readings in different tissues (2, 5, 13, 16). The instrument, the pulse oximeter, consists of red and infrared light-emitting diodes (LEDs), which operate at wavelengths of 660 (red) and 900–940 nm (infrared) to measure the absorption of oxyhemoglobin and deoxyhemoglobin (17). The proportion of absorption of the two light waves that detect oxygenated hemoglobin (arterial blood) and deoxygenated hemoglobin (venous blood) allows the determination of SaO_2 levels and pulse rates (12, 17).

According to Goho (2), SaO_2 values obtained in teeth are usually lower than those obtained at the patient's finger. This observation may have several reasons. First, it is widely accepted that the insulation of the pulp by the surrounding hard tissues is an obstacle to the detection

of vascularity (3). Second, the diffraction of infrared light by enamel prisms and dentin may result in lower SaO_2 readings (2, 15). Goho (2) and Gopikrishna et al. (5) showed previously that PO tests have a lower specificity when compared with cold and electric tests. The authors hypothesized that PO may present lower specificity in cases where the coronal pulp is undergoing changes involving calcification, mainly in cases of dental trauma, deep restorations, or physiologic conditions such as aging.

Several studies have indicated the effectiveness of PO in assessing pulp blood flow (2, 5, 6, 12–16, 18). A critical requirement for the use of PO in dentistry is that the sensor should conform to the size, shape and anatomic contours of the teeth. Moreover, to obtain accurate measurements, the sensor holder should ensure firm placement of the device on the tooth, maintaining the LEDs and the photoreceptor in a position as parallel as possible to each other, so as to guarantee that the light is transmitted through the crown (6, 18).

Based on the above, the objectives of this study were as follows: first, to design and build a custom-made PO dental sensor holder; second, to evaluate the effectiveness of PO in determining pulp blood flow in primary and permanent teeth; and third, to compare the SaO_2 levels obtained in the patient's little fingers and teeth.

Materials and methods

The present research protocol was approved by the Ethics in Research Committee of Universidade Federal de Santa Catarina (UFSC), Brazil (protocol no. 290/2007).

This study was carried out using a BCI 3301 pulse oximeter (Smiths Medical PM Inc., Waukesha, WI, USA) (Fig. 1a) combined with two sensors (3025) calibrated at the Laboratory for Technical Evaluation of the Institute of Bio-Medical Engineering at UFSC. One sensor was used to measure the oxygen saturation (SaO_2) on the patient's little finger (Fig. 1b), and the other to measure it on the teeth (Fig. 1c,d).

The study was performed on 123 teeth from 84 patients, aged 4–13 years, attending the Pediatric Dentistry or Endodontics Clinics at UFSC Brazil. Inclusion criteria required teeth to be free of caries, restorations, developmental defects, mobility, or root resorption. Teeth with any pain symptoms or patients with a previous history of trauma affecting the face, mouth, or teeth were excluded. Periapical radiographs were obtained to ensure the presence of two-thirds of the roots on primary teeth. The permanent teeth were selected by the criteria of Nolla (19): stage 10 (apical end of root completed), stage 9 (root almost complete; open apex), and stage 8 (two third of root completed). Teeth in other stages were not included.

The teeth were divided as follows: group 1 (primary teeth): 23 maxillary central incisors (PCI) and 28 maxillary canines (PC); group 2 (permanent teeth): 25 maxillary central incisors (PECI) and 28 maxillary canines (PEC); and group 3 (control group): 19 root-filled maxillary central incisors (12 permanent teeth and seven primary teeth).

A stainless steel PO dental holder for the 3025 sensor was designed and custom-made to ensure the accurate placement and adaptation of the sensor on primary and permanent teeth for the assessment of pulp blood flow (Fig. 2). This assembly of the existing PO sensor adapted to the custom-made sensor holder is termed as device to position and hold the PO sensor (DPHS) (Fig. 1c).

The DPHS was placed on the teeth (Fig. 1d). The sensor did not come into contact with the teeth, which were isolated using a transparent PVC film placed between the tooth and the sensor. The operating light and the intense fluorescent ambient light were not used during the measurement process to prevent signal interference. The DPHS was positioned on the buccal surface and on the palatal surface of the tooth, maintaining a parallel alignment between the two diodes (Fig. 1c). Subsequently, three SaO_2 values were registered for each tooth within 30 s to 3 min of monitoring.

SaO_2 results and the time were recorded in separate files for each patient and then tabulated. Statistical analysis was performed using Student's paired *t*-test and Pearson's correlation coefficients. Significance was set at 5%.

Results

Pulse oximetry was able to identify all the clinically normal pulps contained in the sample, and all the

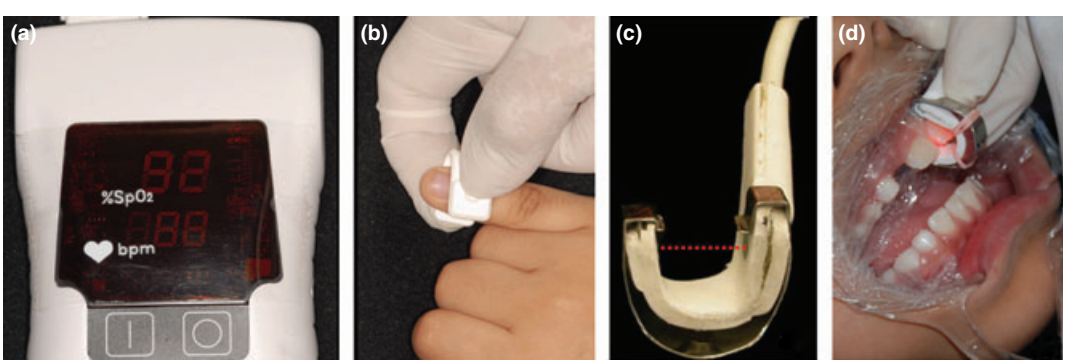

Fig. 1. Photograph illustrating (a) pulse oximetry (PO) (b) the oxygen saturation readings obtained on the finger; (c) device to position and hold the PO sensor (DPHS); (d) the application of DPHS in the tooth.

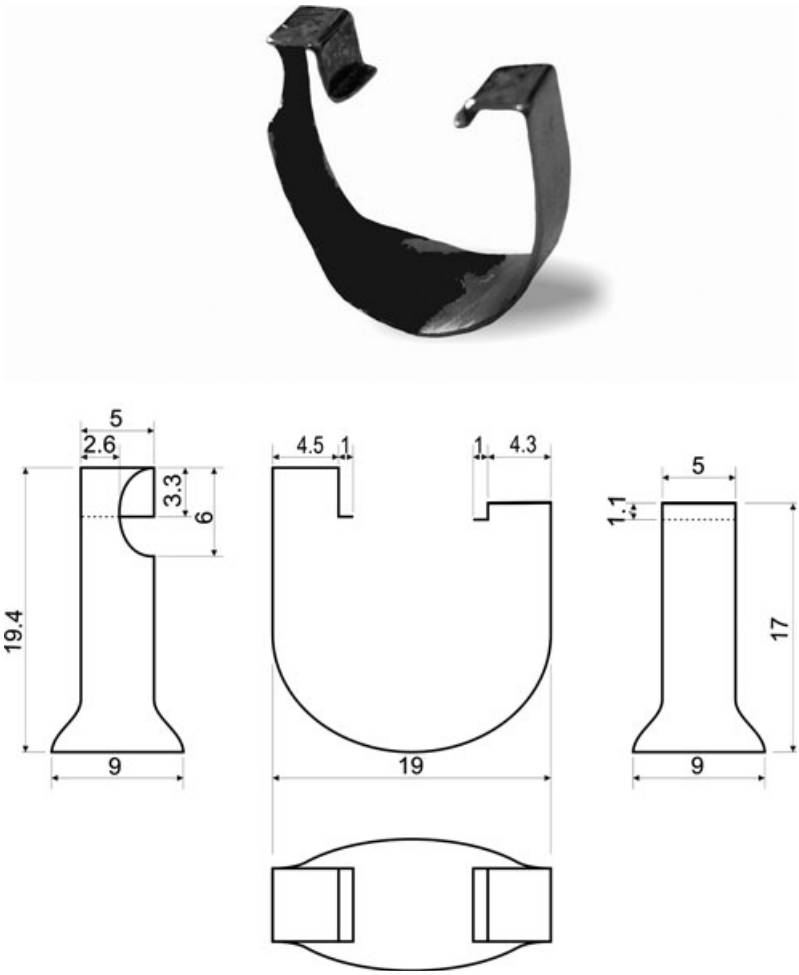

Fig. 2. Photograph and design of the device to position and hold the pulse oximetry sensor, with its dimensions.

endodontically treated teeth (controls) showed no response. Thus, the accuracy rate for the determination of pulp blood flow using the PO was 100%.

Table 1 shows the descriptive measures of SaO_2 levels obtained on the little finger and in the different teeth. The mean SaO_2 values were 85.27% in the teeth and 92.85% in the fingers. There was a significant difference between SaO_2 values obtained on the little finger and those found in primary and permanent maxillary central incisors and maxillary canine teeth ($P < 0.0002$).

Pearson's correlation coefficients between SaO_2 values obtained on the patients fingers and in each one of the teeth assessed showed no correlation between the measurements (Table 2).

The time required for the PO signal SaO_2 was lower in primary teeth (PCI – mean of 58.04 ± 18.01 s; PC – an average of 64.07 ± 20.34 s) than permanent teeth. The difference in the mean values of the PCI and PC (primary group) is not great enough to reject the possibility that the difference is because of random sampling variability. There is not a statistically significant difference between the primary teeth ($P = 0.273$).

In the permanent teeth, the mean PECI was 83.4 ± 35.26 s and the PEC was 76.07 ± 34.97 s. The

Table 1. Descriptive measures for the percentage of SaO_2 readings (%) obtained in primary maxillary central incisors (PCI), primary maxillary canines (PC), permanent maxillary central incisors (PECI), permanent maxillary canines (PEC) and fingers

SaO_2	*n*	Mean	SD	Median	Maximum	Minimum	*t*
PCI	23	83.48	10.11	88	98	63	2.64 ($P = 0.0002$)*
Finger	23	92.48	4.07	92	98	83	
PC	28	86.43	6.61	86	99	73	4.76 ($P = 0.0001$)*
Finger	28	92.86	2.69	93	97	86	
PECI	25	87.76	6.60	89	98	69	4.47 ($P = 0.0005$)*
Finger	25	94.16	2.75	87	98	87	
PEC	28	83.43	8.57	83	99	64	4.85 ($P = 0.0001$)*
Finger	28	92.07	3.89	93	98	85	

*Values of $P < 0.05$ indicate a statistically significant difference.

Table 2. Pearson's correlation coefficients for SaO_2 readings obtained on the little finger and different teeth

	Finger and PECI	Finger and permanent maxillary canines	Finger and PCI	Finger and primary maxillary canines
r Pearson	−0.326	0.340	−0.413	0.153
P value	0.111	0.097	0.050	0.436
t	−1.66	1.73	−2.07	0.79
n	25	28	23	28

PECI, permanent maxillary central incisors; PCI, primary maxillary central incisors.

difference in the mean values of the PECI and PC (permanent group) is not great enough to reject the possibility that the difference is because of random sampling variability. There is not a statistically significant difference between the permanent teeth ($P = 0.452$).

The graph (Fig. 3) plots the median, 10th, 25th, 75th, and 90th percentiles as vertical boxes with error bars of the times for the SaO_2 readings in the finger and different teeth groups.

Discussion

Although the term vitality has been used in several studies (5, 14, 15), in this study 'pulp blood flow' was used, because the PO evaluates blood flow by measuring oxygen saturation.

The BCI 3301 pulse oximeter was selected, because it performed better than other devices in a previous testing, it is smaller and more affordable, and its sensor has suitable dimensions, allowing it to be used in teeth. A custom-made sensor holder was designed to ensure the accurate placement and adaptation of the sensor on primary and permanent teeth. This holder allowed the maintenance of a constant path length for the light emanating from the light-emitting diode sensor to the photoreceptor sensor, thus enabling accurate readings

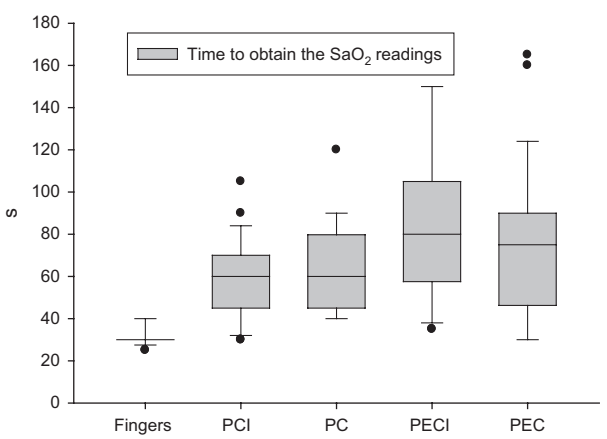

Fig. 3. Time to obtain the SaO_2 readings in the fingers, primary maxillary central incisors, primary maxillary canines, permanent maxillary central incisors, and permanent maxillary canines.

(5). In addition, the DPHS prevented the beam from reaching the gingival tissue and giving false readings.

The PO was first used on the finger according to the manufacturer's instructions. The finger readings were the parameter to compare to those obtained in teeth, a location that was not specified by the manufacturer, but investigated in this study. The little finger was used as standard in all patients.

The findings of this study confirmed the ability of PO to differentiate between clinically normal pulps and teeth from which the pulp had been removed, i.e. those with root canal filling. The data showed that both primary and permanent teeth recorded lower SaO_2 values (65–98%) when compared with readings from the fingers (85–98%). These results are in agreement with previous studies (2, 16). Statistical analysis of the differences between finger and tooth readings, using Pearson's correlation coefficients, showed that there was no correlation between them.

Even though previous statements initially appear to question the qualitative value of SaO_2 readings obtained in teeth, it is important to bear in mind that all teeth (groups I and II) in this study provided consistent SaO_2 readings, whereas all control group teeth recorded no SaO_2 values. This finding confirms that PO is capable of detecting pulp blood flow through enamel and dentin. The lack of statistical correlation between tooth and finger values may reflect inherent optical properties of teeth, as stated previously by Goho (2). Because PO provides reproducible SaO_2 readings in clinically normal teeth, this method acquires immediate clinical value for the assessment of baseline pulp blood flow. Further research is needed to determine SaO_2 values in teeth with pulp diseases (2).

According to the manufacturer's instructions, the SaO_2 variation rate used in operating rooms and intensive care units is accurate within the range 70–99% (± 2). The results that are below 70% would be considered non-specific. However, the results of this study suggest that SaO_2 readings below 70% may be considered as a positive response in the assessment of pulp blood flow.

During the experiment, the children fully accepted the evaluation with PO, even when readings were repeated. This suggests that the non-invasive nature of PO can lead to a greater acceptance and cooperation on the part of pediatric patients during pulp diagnostic procedures.

Existing sensitivity tests require the patient to actively assist in assessing an unpleasant stimulus. For some children and disabled patients, the degree of cooperation required is not always achievable, and even for those patients who can cooperate, the response is subjective (13). Because children adapt their behavior to avoid painful stimuli, their ability to respond properly to conventional pulp testing methods is limited (2, 13).

The oxygen saturation readings were achieved in different times in the teeth (30–165 s) and in the fingers was < 45 s. There is not a statistically significant in the time between incisor and canines in both groups (primary and permanent) in children aged 4–13 years. Theoretically, it could be more difficult to obtain readings in teeth with more thickness of dentin. Despite

the less number ($n = 6$) of permanents incisors and canines (same child), when correlated these data, the time was higher in the incisors, which generally were in Nolla's stage 10 and canines at the stage 8. Perhaps, one factor affecting the decrease time in canines has been the stage of development.

In recently traumatized teeth, the sensitivity tests are inconclusive because of the lack of neurologic response, so in this situation, Gopikrishna et al. (5) suggest that PO can be helpful. Moreover, PO can be beneficial in the assessment of pulp vitality in children's teeth, because sensitivity tests have limitations when used in primary teeth (2).

Conclusion

Pulse oximetry was effective in determining pulp blood flow in primary and permanent teeth using the DPHS. It was not possible to demonstrate a correlation between the level of SaO_2 in the fingers and teeth.

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