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Determination of pulp vitality *in vivo* with pulse oximetry

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Abstract

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Aim To evaluate the use of pulse oximetry as a test for pulp vitality, by comparing in the same patient, the levels of oxygen saturation of the index finger and of the maxillary central incisor and canine teeth without clinically detectable pulp inflammation.

Methodology Seventeen male and female patients aged between 26 and 38 years participated and a total of 32 maxillary central incisor and 32 canine teeth were analysed. Selection criteria required the teeth to have healthy crowns, or with restorations no more than 2 mm in diameter and no clinical and radiographical signs or symptoms of pulp or periapical inflammatory changes. The negative control group consisted of 10 root filled teeth. Measurements were first taken from the index finger of patients. Their teeth were then subjected to a thermal test with refrigerant gas and then to a vitality test with pulse oximetry. Data were analysed by Pearson's and paired *t*-tests.

Results There were no significant statistical correlations between blood oxygen levels in the index finger and in the teeth of the patient ($P > 0.05$). There was a statistically significant difference in the oxygen levels between the two tooth groups studied and the index finger ($P \leq 0.002$). Mean oxygen values in the index finger of patients were 95% (SD = 1.6), oxygen values in the maxillary central incisor were 91.29% (SD = 2.61) and mean oxygen values in maxillary canine were 90.69% (SD = 2.71).

Conclusion The method determined consistently the level of blood oxygen saturation of the pulp in maxillary central incisor and canine teeth and can therefore be used for pulp vitality testing. Further studies are required to assess the effectiveness and validity of pulse oximetry in determining pulp vitality in traumatized teeth.

Keywords: pulse oximetry, dental pulp test, endodontics.

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Introduction

Diagnosis of the condition of the pulp is of fundamental importance in endodontics for the determination of the appropriate treatment. Amongst the diagnostic methods most commonly used are electrical and thermal tests, the latter of which uses heat and cold (Dachi *et al.* 1967, Lundy & Stanley 1969). Because of the poor reliability of thermal tests, electric tests are often preferred. However, factors affecting the application of the electric current and the occurrence of false negative or false positive results have had a negative impact on the use of electric pulp testers (Cooley & Robison 1980).

In reality, pulp vitality depends solely on blood supply. The tests for pulp sensitivity do not always reflect the degree of pulpal disease, but serve as a guide or an indication of the degree of vitality through responses under certain circumstances. It is possible to evaluate the blood supply to pulpal tissues with physiometric tests, which measure blood flow by applying a light of known wavelength to the tissue

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being examined (Noblett *et al.* 1996). These tests register the tissue level of oxygen and are therefore less vulnerable to the limitations and variables inherent to other pulp sensitivity tests (Mills 1992).

Amongst physiometric tests, pulse oximetry is a noninvasive method for the determination of oxygen saturation and pulse rate of a tissue (Mills 1992). It consists of two light emitting diodes, a red and an infra-red one, which operate at 500 on/off cycles s^{-1}. The emissions of these light sources are captured by a photodiode receiver and converted by electronic circuits into measurements for arterial oxygen saturation (SaO_2) and pulse rates (Mills 1992).

According to Alexander (1989), the proportion of absorption of the two light waves that detect oxygenated haemoglobin (arterial blood) and unoxygenated haemoglobin (venous blood) gives the percentage of blood oxygen. The pulse rate is determined by the exchange between highly oxygenated arterial blood and unoxygenated venous blood and by the change in light reception.

According to Schnapp & Cohen (1990), pulse oximetry is a relatively recent advance in noninvasive monitoring. The principle of this technology is based on a modification of Beer's Law and on the absorption characteristics of haemoglobin in the red and infra-red range. Red and infra-red light waves are used to transilluminate a tissue and detect absorption peaks according to blood circulation which allows the determination of oxygen saturation and pulse rates.

Schnettler & Wallace (1991) studied 49 maxillary central incisors in humans and evaluated pulp vitality with thermal, electric and pulse oximetry tests. Oxygen saturation and pulse rate readings were obtained for vital teeth but not for root filled teeth, confirming the potential of pulse oximetry to diagnose the state of pulp pathology as well as to assess pulp vitality of traumatized teeth.

Mills (1992) confirmed the advantages of this method for determining pulp vitality by monitoring the blood supply to the teeth, but identified various disadvantages regarding the apparatus in clinical use such as movement of the device, weak signal, need for a special dental probe and the need for a gel to improve the transmission of light between the probe and the tooth.

Noblett *et al.* (1996) developed a dental sensor to evaluate the potential and precision of pulse oximetry concluding that pulse oximetry could be adapted to detect pulp blood circulation and therefore diagnose pulp vitality. The presence of blood circulation in the pulp chamber would determine pulp vitality in spite of the absence of sensorial response.

Goho (1999) sought to evaluate pulp vitality in young permanent teeth with pulse oximetry. He reported that this method was effective and useful for those patients whose incomplete pulpal innervation or lack of cooperation reduced the effectiveness of conventional tests for pulp vitality. The readings obtained were consistent in terms of SaO_2 which confirmed the presence of pulpal blood circulation. However, the need to construct a probe that better adapts to the tooth was noted.

The effectiveness of pulse oximetry in determining pulp vitality when compared with electric tests was also observed by Radhakrishnan *et al.* (2002). As a reproducible level of SaO_2 is obtainable in vital teeth, this method can be of extreme importance, principally for traumatized teeth.

The objective of this study was to evaluate the use of pulse oximetry as a test for pulp vitality, comparing the levels of oxygen saturation obtained between teeth without any clinical inflammatory changes (maxillary central incisors and maxillary canines) and comparing these levels with those obtained from the index finger of the same patients.

Materials and methods

This study was carried out on 17 male and female patients, aged 26 to 38 years, from which 32 maxillary central incisors and 32 maxillary canines were examined. All patients signed an informed consent form before examination procedures and the research project (Nr. 24/03) was approved by the Ethics in Research Committee, School of Dentistry, University of São Paulo, Brazil.

All the teeth selected had clinically intact crowns or restorations of no more that 2 mm in diameter, which were located in areas away from where the vitality tests were to be applied.

Teeth were excluded from the study if they presented any pain symptoms, denoting some kind of inflammatory pulp alteration, a history of dental trauma, dental caries or colour change in the tooth crown, advanced periodontal diseases, swelling or increased mobility, tenderness to apical palpation and vertical or horizontal percussion.

Prior to pulp vitality testing with pulse oximetry, the teeth were subjected to a thermal test with tetrafluoroethane refrigerant gas (Green Endo Ice; The Hygenic Corporation, Akron, OH, USA).

Althought initially 32 maxillary incisors and 32 maxillary canines were selected, four incisors were discarded. In these four teeth, no reading for oxygen saturation was possible, despite their positive response of these incisors to thermal tests with refrigerant gas.

After the thermal test with refrigerant gas, the pulse oximetry test for pulp vitality was applied. A special device (Oxigraph model; System Partner Ltda., São Caetano do Sul, SP, Brazil) was used in combination with a sensor adapted for dental use (System Partner Ltda.).

Because of technical problems relating to the differences between the teeth and the fingers used, the oximetry was adjusted for lower light intensity on the tooth. This change was made in the Oxigraph monitor program by company engineers.

The capture profusion on a finger is greater than on a tooth. This compelled us to increase the sensitivity levels of the pulsing element. It was thus necessary to amplify the pulse signal by 2.5 times, normally used in the worst conditions of pulse captured on a finger. Therefore to capture a reasonable pulse signal in the tooth, the pulsing signal had to be amplified through modification to the amplifying circuits of the pulsing element of the equipment.

Measurements were taken initially from the patient's index finger with the same sensor to prevent disparate test results, and the data obtained for SaO_2 were recorded for subsequent evaluation.

Measurements were then taken from the teeth of the same patient. The area under examination was partially isolated with cotton rolls. The patient was instructed to avoid moving the head during the test and the operating light and intense fluorescent ambient light were not used during measurement to prevent interference to signal capture. The sensor was positioned on the buccal surface (emitting diode) and the palatal surface (receiving diode), maintaining parallel alignment between the two diodes; the signal was obtained in approximately 5 s. A negative control group was included that consisted of 10 root filled teeth from another group of patients.

Data from the measurement of SaO_2 were recorded on a separate file for each patient. These data were then recorded in tables and statistical analysis with paired *t*-test and Pearson's tests was carried out.

Results

All the teeth that were selected gave positive responses to the thermal test with refrigerant gas, except the root filled teeth. The results of the measurements performed on the index finger of the patients revealed mean blood oxygen values of 95% (SD = 1.6). This result was compared with the mean values of blood oxygen obtained from the maxillary central incisors and canines, which were 91.29% (SD = 2.61) and 90.69% (SD = 2.71), respectively. In the negative control group, 0% of blood oxygen (pulse signal not obtained) was rated.

Table 1 Descriptive measures for the percentage of SaO_2 readings (%)

SaO_2	*n*	Mean	SD	Median	Minimum	Maximum
Finger	16	95.0	1.6	95.0	90.0	97.0
Teeth 11	14	91.2	2.6	91.5	85.0	95.0
Teeth 21	14	91.4	2.7	92.0	86.0	96.0
Teeth 13	16	90.6	3.0	90.5	86.0	96.0
Teeth 23	16	90.8	2.5	91.0	86.0	94.0

SaO_2, arterial oxygen saturation.

Table 1 shows the descriptive measurements of the SaO_2 levels obtained from both the index fingers and the incisor and canine teeth. Overall, it can be seen that the greatest mean percentage of SaO_2 was observed for the index fingers (95.0%). The canine and incisor teeth gave mean values of approximately 91.0%.

Based on Table 2, it can be concluded that the mean SaO_2 values obtained for the index fingers were significantly different from those obtained for the maxillary canines or maxillary incisors (all $P \leq 0.002$).

Table 3 shows the values for Pearson's correlation coefficients between the SaO_2 measurements obtained

Table 2 Paired mean difference and 95% confidence intervals for the percentage of SaO_2 readings (%)

	Mean difference	95% CI	*P*-value[a]
Finger - Teeth 11	3.6	(2.1–5.1)	<0.001
Finger - Teeth 21	3.4	(1.5–5.3)	<0.002
Finger - Teeth 13	4.4	(2.7–6.0)	<0.001
Finger - Teeth 23	4.3	(3.0–5.5)	<0.001

SaO_2, arterial oxygen saturation; CI, confidence interval.
[a]*P*-value corresponding to the paired *t*-test.

Table 3 Pearson's correlations for the readings of saturation of arterial oxygen of the index fingers and the teeth

	Index finger and teeth 11	Index finger and teeth 21	Index finger and teeth 13	Index finger and teeth 23
Pearson's correlation	0.320	−0.104	0.204	0.365
P-value	0.264	0.724	0.450	0.165
n	14	14	16	16

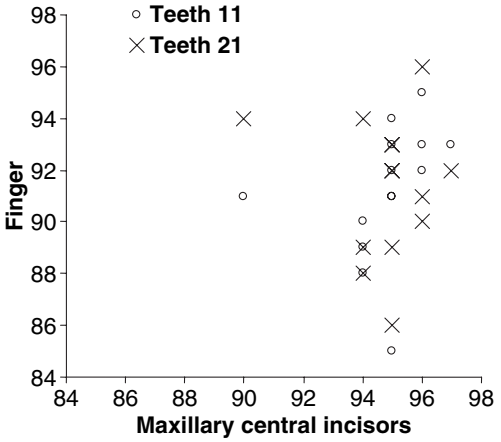

Figure 1 Dispersion of arterial oxygen saturation measurements for finger and maxillary central incisors.

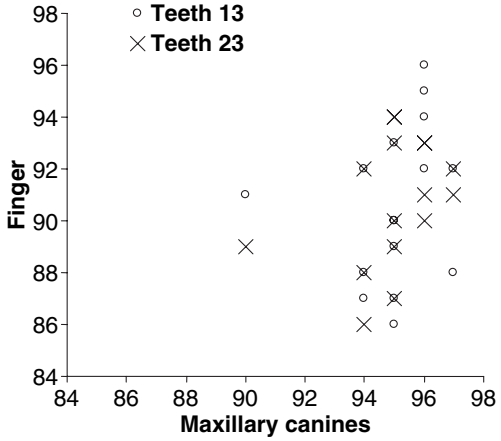

Figure 2 Dispersion of arterial oxygen saturation measurements for finger and maxillary canines.

for the index fingers and for each one of the teeth considered. Figures 1 and 2 present dispersion graphs that aid in visualizing the association between the SaO_2 measurements. Overall, the index finger measurements did not correlate with the tooth measurements.

Discussion

Correct diagnosis is the basis for rational therapy and is essential prior to treatment. This is in accordance with observations by Baume (1970) and Dummer *et al.* (1980) who stated that the indication for endodontic treatment depended on the causes, effects and dynamics of pulpal physiopathology and on the symptoms presented by the patient, thus forming the basis for the differential diagnosis.

The reliability and feasibility of thermal tests using ice was demonstrated by Austin & Waggener (1941). However, limitations related to the presence of secondary dentine were reported. Other authors (Dachi *et al.* 1967, Pesce *et al.* 1985) have also reported limitations regarding the occurrence of false negative results in canine teeth and in young patients.

The use of a stick of ice as a source of cold stimulus yielded encouraging results. Barletta (1992) observed a rapid and significant decrease in intrapulpal temperature with no corresponding damage to the tooth.

With the advent of refrigerant gases employed as aerosols, an improvement in the evaluation of pulpal response has been observed, especially in teeth with thick dentine (Medeiros & Pesce 1993, Caldeira *et al.* 1995) and in teeth with incomplete root formation (Aun *et al.* 1994) with both dichlorodifluoromethane (Castagnola & Negro 1972) and tetrafluoroethane (Buckingham 1982).

Caldeira (1997) compared the clinical pulpal response of patients subjected to ice and dichlorodifluoromethane vitality testing and observed that dichlorodifluoromethane was more effective, and that the frequency of positive responses decreased with age and according to the teeth studied.

The interpretation of data obtained from tests for pulp sensitivity allows the establishment of more accurate diagnosis. However, as seen previously, these data are subject to variations such as the sensitivity threshold of the patient, interpretation of the response by the dentist and other factors that can lead to incorrect interpretation of the data.

Moreover, Eli (1993) reported that fear, anxiety and the anticipation of pain are significant emotional and cognitive mediators in the behaviour of the patient with regard to pain.

The objectivity of the pulse oximetry method presents advantages over other methods which are based on sensory nervous responses that vary according to individual and subjective factors. The noninvasive nature of pulse oximetry may also lead to greater acceptance and cooperation by the patient in diagnostic procedures.

Despite the advantages of pulse oximetry over other methods for determining pulp vitality, factors related to head movement and the swallowing reflexes of the patient, probe-tooth fit and ambient light interfere with the quality of the signal obtained (Schnettler &

Wallace 1991, Mills 1992). Furthermore, Odor *et al.* (1999) evaluated the laser light propagation in the tooth surface of some animal species and concluded that those with small teeth showed inconsistent results.

According to Goho (1999), there is a need to adapt the sensor which is generally used from the ear lobe to the tooth to facilitate parallel alignment between the emitting and receiving diodes. However, in that study, the adaptation consisted only of the removal of the external covering of the sensor to reduce its size. Results of blood oxygen of 94% (mean) were obtained for central incisors with incomplete root formation, where thermal tests become imprecise because of individual root characteristics, and readings of 93% (mean) were obtained for deciduous incisors. The blood oxygen saturation levels from teeth routinely registers lower than the readings from the patient's finger. There was no significant statistical correlation between the values obtained for blood oxygen saturation between the tooth and those obtained for the index finger of the patient.

This study was similar to that reported by Goho (1999), except for the age of the patients which included adults with complete root formation; the tooth type, which comprised maxillary central incisors and canines; and, above all, changes made to the sensor through altering various parameters to make measurement possible from the dental pulp.

Results showed levels of blood oxygen similar but lower to those found by Goho (1999), probably because they were teeth with complete root formation where blood supply is modified because of the constriction of the apical region (Goho 1999).

Despite the positive response of these incisors to thermal test with refrigerant gas, no reading for oxygen saturation was possible for them. This was probably because of factors related to the positioning of the sensor, as it might not have been possible to correctly align the diodes so as to obtain parallelism or a large dentine layer existed as there was a low perfusion capacity from the tissue.

The results of this study show that there was a consistency between the values of blood oxygen saturation obtained from the index finger of the patient and those obtained from the teeth, demonstrating a low correlation between them. This differs from the results obtained by Goho (1999), probably because of factors related to the sensor such as the amplification of the pulse signal which optimizes the capture of the intrapulpal pulse.

Moreover, Kahan *et al.* (1996) constructed and tested a probe for teeth using an oximeter Biox 3740 (Medical Supplies & Equipment Co., Houston, TX, USA) to determine the pulse waves of maxillary and mandibular incisors and a significant difference by the pulse synchronization was observed.

Amongst the main difficulties with the sensor probe, there was the difficulty in aligning the emitting and receiving diodes because of the anatomy of the teeth studied, where the concavity of the palatal surface and the presence of the cingulum hindered proper contact of the sensor, in addition, prevent it from being stabilized.

Many reports (Schnettler & Wallace 1991, Mills 1992, Goho 1999, Radhakrishnan *et al.* 2002) have noted the need for a specially designed sensor for dental use (Noblett *et al.* 1996) to minimize the factors that interfere in obtaining a reliable signal.

In this study, to capture a reasonable pulse signal in the tooth, the pulsing signal had to be amplified through modification of amplifying circuits of the pulsing element of the equipment. This value still cannot be considered ideal but it was the most that could be achieved by current electronic circuits. An even greater increase in this gain would mean a lower signal/noise ratio as well as greater influence of ambient light and movement interference.

It is believed that a 500-fold gain in the pulsing rate would be ideal for work carried out under these conditions; however, changes would have to be made in the amplifiers, and these that could not be made in this model of the equipment.

A change in the equipment program was necessary so that the equipment could capture the pulse in the tooth and the finger in such a way that made it possible to create a sole source of measurement and comparison of data collected in the study (System Partner – Quality Engineer).

Conclusions

This study confirms the potential use of pulse oximetry as a test for pulp vitality and demonstrated that the method determined the level of blood oxygen saturation of the pulp in maxillary central incisors and maxillary canines (without clinically detectable inflammatory changes). There was no statistical correlation between the level of blood oxygen saturation obtained from the index finger and that obtained from the teeth of patients. There was no statistically significant difference between the value of blood oxygen saturation obtained from maxillary central incisors and maxillary canines.

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