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ORIGINAL RESEARCH

Pulse Oximetry: A Diagnostic Instrument in Pulpal Vitality Testing—An *in vivo* Study

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ABSTRACT

Background and objective: The purpose of this study was to compare the clinical effectiveness of the novel pulse oximeter probe (OxyTip+) over the conventional techniques of electric pulp tester and thermal testing of tooth vitality.

Methods: A total of 50 children of 7 to 12 years of age (group I) and 50 adults above 18 years of age (group II) with normal maxillary central incisors were subjected to vitality tests each by thermal, electrical and pulse oximetry. Also, 20 patients (group III) with known nonvital anterior teeth having complete endodontic restorations were tested as above. The procedure was recorded twice and the readings were tabulated and statistically analyzed using the Pearson's correlation tests.

Results: The correlation between the SaO_2 readings and electrical readings were found to be negative with $r = -0.201$ and $r = -0.39$ for group I and group II respectively. The r value for group I was not statistically significant, but for group II it was significant with $p < 0.01$. It showed that the values of electrical pulp tester reading increased as the SaO_2 values decreased.

In group I, all cases gave a positive response to thermal test with a SaO_2 measure on tooth. But in group II, 2% of cases showed a negative response to thermal test though SaO_2 measure on tooth gave reading.

Conclusion: The present study indicates that pulse oximetry with the OxyTip+ probe may be adaptable to the detection of pulpal blood circulation for all age groups, and thus diagnosis of pulp vitality.

Keywords: Pulp vitality, Pulse oximetry.

INTRODUCTION

The assessment of pulp vitality is a crucial diagnostic procedure in the practice of dentistry[1] and for treating traumatized teeth.[2] Assessment of the teeth vitality is complicated by the fact that the dental pulp is enclosed within calcified tissues, and do so indirectly.[3] Traditionally, the dentists have relied on testing methods designed to reproduce symptoms associated with pulpal pathosis. The methods include thermal stimulation (heat or cold application); electrical stimulation, anesthetic testing or direct dentine stimulation (test cavity).[1] These modalities fall short of the ideal pulp tests on several criteria. All these testing methods have the potential to produce an unpleasant and occasionally painful sensation, and eventually obtaining inaccurate results by a drip of ice onto adjacent teeth or gingival tissues,[4] or when electric current applied to the tooth surface is conducted to the periodontal ligament, thus stimulating periodontal nerve fibers.[3] False-negative responses may also occur in the cases of calcific metamorphosis, in the teeth with immature root formation, or subsequent to an impact injury.[5,6] All these are subjective tests that depend upon patient's perceived response to a stimulus as well as the dentist's interpretation of that response.

Another problem with these traditional pulp testing methods is that they only indirectly monitor pulp vitality by measuring the neural responses and not circulation. Since pulp vitality is purely a function of the vasculature health, a vital pulp with an intact vasculature may test nonvital if only its neural component is injured. This situation is commonly encountered with recently traumatized teeth[7] causing momentary anesthetic effect. On the other hand, the pulp nerve fibers are more resistant to necrosis than the vascular tissue.[8] And, thermal or electric testing of only the pulp neural response may also result in false-positive results if only the pulp vasculature is damaged.

For electric and thermal testing to be effective, the pulp must have a sufficient number of mature neurons. However, both the primary and young permanent teeth are not fully innervated with alpha myelinated axons, which are responsible for the pulpal pain response. Permanent teeth may not exhibit full alpha myelinated axon innervation until 4 to 5 years after eruption. Current routine methods for assessment of pulp vitality rely on stimulation of A-delta fibers and give no direct indication of blood flow within the pulp. This reduced number of pain receptors makes them less responsive to stimuli and, therefore, more susceptible to take negative results from thermal and electrical testing.[9] Considering all these limitations, present pulp testing with thermal and electric methods cannot be considered reliable vitality tests for the patients.

A direct measure of the pulpal circulation is the only real measure of pulp vitality. The pulse oximeter is a noninvasive oxygen saturation monitoring device widely used in medical practice for recording blood oxygen saturation levels during the administration of general anesthesia.[2]

Recently, few studies were done using pulse oximetry to detect the oxygen saturation of the pulp. Based on these pioneering studies, the present original work was undertaken to compare the clinical effectiveness of the pulse oximeter probe (OxyTip+®) over the conventional techniques of electric pulp tester and thermal testing of tooth vitality by correlating the percentage of oxygen saturation (SaO_2) readings obtained from the pulp by pulse oximeter, with electric pulp tester readings and response to thermal test.

METHODOLOGY

The present *in vivo* study was conducted in the Department of Conservative and Endodontics and the Department of Oral and Maxillofacial Surgery, College of Dental Sciences, Davangere, in the year 2005.

Materials used in the Study (Fig. 1)

1. Pulse oximeter monitor (Datex Ohmeda)
2. OxyTip+® (Datex Ohmeda) (Fig. 2)
3. Electric pulp tester (Parkell)

Fig. 1: Materials used

4. Anesthetic gel (Topicale gel, Premier dental products)
5. Gutta-percha sticks
6. Spirit lamp
7. Lip retractor (Capri)
8. Guaze/cotton rolls
9. Examination gloves.

Source of Data

A total of 50 children of 7 to 12 years of age (group I) and 50 adults above 18 years of age (group II) with normal maxillary central incisors were subjected to vitality tests each by thermal, electrical and pulse oximetry. Also, 20 patients (group III) with known nonvital anterior teeth having complete endodontic restorations were tested as above.

Method of Collection of Data

The children and adults selected for this study are those who came as outpatients in the Department of Conservative Dentistry and Endodontics and Department of Pediatric Dentistry, College of Dental Sciences, Davangere, Karnataka. Selection criteria required the teeth to be free of caries, calculus, restorations, developmental defects and mobility. As the procedure required patient intervention, ethical clearance was obtained from the institution and written consent was also taken from the patient/ parent.

Methods

The oxygen saturation (SaO_2) values were first measured on the index finger. This served as the control for the comparison of oxygen saturation values that will be measured on the teeth (Figs 3 and 4).

Teeth were isolated using gauze lip retractor, and air dried (Figs 5 and 6). The SaO_2 of the teeth was recorded by placing the sensor probe. The probe was placed on the crown so that the light would travel from the facial and lingual through the middle of the crown. The values were recorded after 30 seconds of monitoring each tooth (Figs 7, 8 and 11).

Fig. 2: Close-up view of OxyTip+®

Fig. 3: SaO_2 (F) of a patient of group I

Fig. 4: SaO_2 (F) of a patient of group II

Fig. 5: Isolation of teeth for group I

Fig. 6: Isolation of teeth for group II

Fig. 7: SaO_2 (T) of a patient of group I

Fig. 8: SaO_2 (T) of a patient of group II

Fig. 9: EPT test of a patient of group I

Fig. 10: Thermal test of a patient of group II

Using thermal and electric pulp tester, the vitality of the same tooth was also recorded (Figs 9 and 10). The procedure was recorded twice and the readings were tabulated and statistically analyzed using Karl Pearson correlation.

RESULTS

The mean SaO_2 value measured from patient's finger was 96.9% (SD ± 1.1), 97.6% (SD ± 0.4) and 97.6% (SD ± 0.63) for group I, II and III respectively, as shown in Table 1.

The SaO_2 values on tooth of group I averaged 87.1% (SD ± 2.8) and of group II averaged 87.8% (SD ± 1.8), as shown in Table 1.

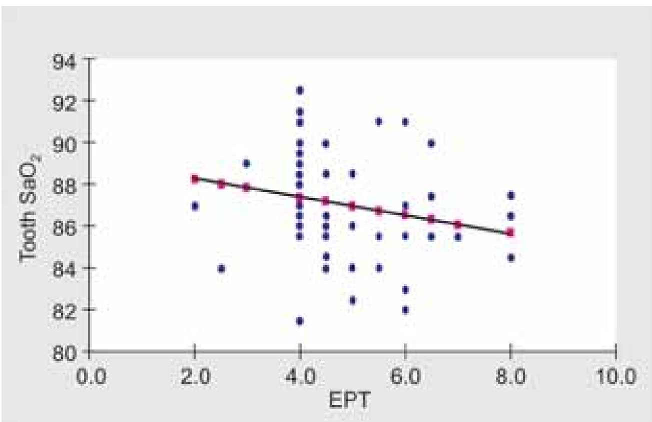
Table 1: Mean, standard deviation and range in groups I, II and III

Groups		*SaO_2*		*EPT*	*Thermal*	
		Index finger	*Tooth*		*+ve*	*-ve*
Group I	Mean ± SD	96.9 ± 1.1	87.1 ± 2.8	4.8 ± 1.3	50	Nil
	Range	93.5-98.0	81.5-92.5	2-8		
Group II	Mean ± SD	97.6 ± 0.4	87.8 ± 1.8	1.4 ± 0.7	49	01
	Range	96.5-98.5	84.0-93.5	1.0-4.5		
Group III	Mean ± SD	97.6 ± 0.63	–	–	Nil	20
	Range	96.0-98.5	–	–		

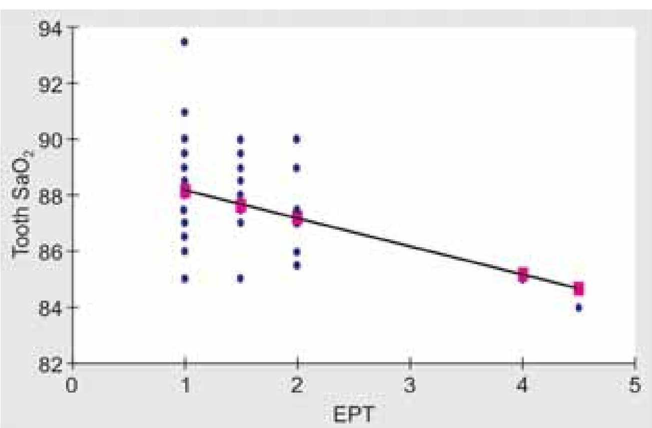
Table 2: Karl Pearson correlation in groups I and II

	Group I		*Group II*	
	r	*p*	*r*	*p*
SaO_2 index finger/ SaO_2 tooth	–0.05	0.75NS	+0.32	< 0.05, S
SaO_2 tooth/EPT	–0.201	0.16NS	–0.39	< 0.01, S

S: Significant



Graph 1: Relationship between EPT and SaO_2 (T)—group I



Graph 2: Relationship between EPT and SaO_2(T)—group II

Twenty nonvital teeth (group III) which were taken as control with complete endodontic fillings recorded SaO_2 values of 0% and showed no response to electrical and thermal testing procedures, as shown in Table 1.

The EPT readings on tooth of group I averaged 4.8 (SD ± 1.3) and of group II averaged 1.4 (SD ± 0.7) as shown in Table 1.

Fig. 11: SaO_2 (T) of a patient of group III

The correlation between the SaO_2 readings and electrical readings were found to be negative with r = –0.201 and r = –0.39 for group I and group II respectively, as shown in Table 2. The r-value for group I was not statistically significant, but for group II it was significant with p < 0.01. It showed that the values of electrical pulp tester reading increased as the SaO_2 values decreased (Graphs 1 and 2).

In group I, all cases gave a positive response to thermal test with a SaO_2 measure on tooth. But in group II, 2% of cases showed a negative response to thermal test though SaO_2 measure on tooth gave reading.

DISCUSSION

Detection of blood circulation would provide an objective differentiation between necrotic and vital pulp tissue. To detect blood circulation in the clinical setting, the development of a non-invasive method of detecting circulation is required. Recent attempts to develop a method for optical determination of pulpal circulation have involved the use of laser Doppler flowmetry,[10-12] dual wavelength spectrophotometry[13] and pulse oximetry.[1,2,9,14] Although laser Doppler flowmetry has met with some success in medical applications, its use in dentistry has been hampered by the sizable expense, lack of reproducibility, and sensitivity of the device to motion. Dual wavelength spectrophotometry has been examined only in the laboratory setting thus far, and only detects the presence of hemoglobin, not the circulation of blood.[1]

Pulse oximetry is a relatively recent advance in noninvasive monitoring. The principle of this technology is based on modification of Beer's law and the absorbance characteristics of hemoglobin in the red and infrared range. The pulse oximeter uses red and infrared range wavelength to transilluminate a tissue bed, detecting absorbance peaks due to pulsatile blood circulation, and uses this information to calculate pulse rate and oxygen saturation. Because the pulse oximeter detects pulsatile absorbance, this technology is well suited for the detection of pulpal blood circulation provided a sensor could be adapted to tooth structure.[1] To date, there are only four studies reported in literature using the same. Of them one was *in vitro* study and three others were *in vivo*.

Also, modern endodontics is becoming influenced by novel biological, genetic and metabolic approaches toward new strategies for regeneration of dental pulp.[15] Keeping this in mind, the technology with which pulse oximeter works can be adapted for the true objective evaluation of the progress of regeneration, which could be a leap into the future of endodontics.

Although studies published regarding the use of pulse oximetry count to four, it has not become a routine yet. This is probably because all of them required a modification of the probe. With this background knowledge, the search was focused on the design of the probe of the pulse oximeter which would adapt to the tooth surface without modification. This gave a handful of probe designs by various manufacturers. Further when these were analyzed for our purpose, the range of pediatric probes and the ear probes did not justify our requirements. Of all of them, OxyTip+®, manufactured by Datex-Ohmeda, was found promising. This probe has 'Y' shaped design at the working end which, as claimed by the manufacturer, can be used at various sites.

So, the present study was performed with the objective to compare the clinical effectiveness of the novel pulse oximeter probe (OxyTip+®) over the conventional techniques of electric pulp testing and thermal testing of tooth vitality by correlating the percentage of oxygen saturation (SaO_2) readings obtained from the pulp by pulse oximeter, with electric pulp tester readings and response to thermal test.

The results of this study confirmed the ability of the pulse oximeter to differentiate between vital and nonvital teeth. The average SaO_2 values of group I was 87.1 ± 2.8, which was comparable to values obtained in earlier study[9] in which average was 81.0 ± 1.7, and average SaO_2 value of group II was 87.8 ± 1.8, which was comparable to values obtained in earlier study in which average SaO_2 value was 94%.[14]

Both groups I and II had tooth SaO_2 values lower than SaO_2 values recorded on patient's fingers. The lower tooth SaO_2 values may be attributable to several causes. Diffraction of infrared light by enamel prisms and dentin may cause decreased SaO_2 readings. This can also be attributed to light ray scatter through the gingiva as suggested by an earlier study.[2]

For group I, the statistical correlation of tooth SaO_2 and finger SaO_2 gave a r-value of –0.05 with a p-value of 0.75, which was not significant. The reason being, the OxyTip+®, although flexible enough was still large to ideally position on the partially erupted permanent incisors. This may have resulted in less than perpendicular direction of the light source through the crown, resulting in lower SaO_2 readings as suggested in an earlier study.[2]

For group II, statistical correlation of tooth SaO_2 and finger SaO_2 gave a r-value of +0.32 with a p-value of less than 0.05, which was found significant. This may be due to the correct adaptation of the probe on fully erupted permanent incisor.

Although such correlations initially appear to question the qualitative value of SaO_2 readings obtained from the teeth, it must be remembered that all vital teeth provided consistent SaO_2 readings and all nonvital teeth recorded no SaO_2 readings (Fig. 11). This is in accordance with the earlier studies.[1,9] This confirms that pulse oximetry is capable of detecting pulp vitality through enamel and dentin.

Then, the SaO_2 values obtained on teeth were correlated with the electric test readings. The correlation between the SaO_2 readings and electric test readings were found to be negative ($r = -0.201$ and $r = -0.39$ respectively for group I and group II), i.e. as the values of electric pulp test reading increased, the SaO_2 values decreased. This correlation is in accordance with an earlier study.[9] Such a variation could be attributed to the high incidence of false-positive and false-negative response associated with electric pulp testing. This as supported by earlier study[16] which shows a positive predictive value of 0.88 and negative predictive value of 0.84. This means that the probability that no sensitive reaction represents a necrotic pulp was 88%, while the probability that a sensitive reaction represented a vital pulp was 84% with electric test.

The possible causes for such a variation are discussed as follows. In case of group I, the increase in the EPT readings is due to the fact that myelinated nerve fibers entering the tooth may not reach the maximum number until 5 years after tooth eruption. Furthermore, there is impedance to the electric current caused by the larger pulp of immature tooth.[17] On the other hand, increase in EPT readings in group II, can be attributed to the calcification of root canal system resulting from pulpal irritation or aging.[18] With age, there is a gradual decrease in the size of the pulp chamber and the number of nerve fibers in the pulp, probably because of increased reparative dentin deposition.[17]

In group I, all cases gave a positive response to thermal test with a corresponding SaO_2 measure on tooth. But in group II, 2% of cases showed a negative response to thermal test though SaO_2 measure on the tooth gave a reading. Such a variation could again be attributed to the high incidence of false-positive and false-negative response associated with heat test. This, as supported by earlier study, shows a positive predictive value of 0.48 and negative predictive value of 0.83.[16] This means that the probability that no sensitive reaction represents a necrotic pulp was 48%, while the probability that a sensitive reaction represented a vital pulp was 83% with heat test. The reasons here are again because of the same factors described above for electric test.

There are some limitations inherent in the technology of pulse oximetry. Intrinsic limitations include excessive carbon dioxide in the blood stream interfering with deoxygenation values. Also, nail polish may interfere with the finger readings. Extrinsic interferences may be due to the interferences of the probe, over head xenon arc lamps and problems with the probe itself. These might include artifact signals within the electronics of the probe or be caused by interfacial geometry difficulties, if the anatomical characteristics of the teeth prohibit adequate isolation of beam to receptor path. Also, full crown restorations impermeable to light do not register any readings.[14]

Keeping in mind the lower SaO_2 values obtained for tooth, further studies must be directed toward understanding the dynamics of light passage through enamel and dentin in terms of transmission, reflection, diffraction, absorption and other such parameters. The results of which should be applied to the monitor of pulse oximeter so that it would be calibrated specifically for the purpose of tooth SaO_2 measurement.

Also, to address the nonadaptability of the probe, for the partially erupted/fractured tooth, reflectance oximetry which uses reflected rather transmitted light on a single sided probe should be studied. It uses LEDs of 735 and 900 nanometers, and presently being tried for fetal oximetry. The probe is placed over the temple or cheek of the fetus. Other than using specific reflections spectra, the principles are same for transmission oximetry.[19] Thus, it can be placed on more proximal anatomy such as the labial surface of the tooth.

With this discussion and obtained results from the present study, it can be concluded that pulse oximetry with the OxyTip+® probe may be adaptable to the detection of pulpal blood circulation for all age groups, and thus diagnosis of pulp vitality. This is especially true in cases of impact injury to the teeth during which the nerve supply to the pulp may be injured, but the blood supply remains intact. Demonstration of blood circulation within the pulp chamber would establish the vitality of the pulp even in the absence of a sensory response. The objectivity of this method of diagnosis offers a distinct advantage over the currently available methods, such as thermal and electric stimulation, which rely on sensory nerve response that varies with the patient's personality and experience. The lack of dependence on a sensory response eliminates the need for the application of a potentially unpleasant stimulus to the patient. The noninvasive nature of pulse oximetry may also result in greater patient acceptance and cooperation with diagnostic procedures.

CONCLUSIONS

Within the limitations of this study, following conclusions were drawn:

1. Datex Ohmeda 3800 pulse oximeter, with novel probe OxyTip+®, has immediate clinical value in providing base line vitality data, since reproducible SaO_2 readings were obtained on vital teeth
2. In view of the limitations of the conventional pulp testing methods, pulse oximeter with OxyTip+® offered an objective evaluation of pulpal circulation
3. The noninvasive nature of pulse oximetry may also result in greater patient acceptance and cooperation with diagnostic procedure
4. Keeping in mind the improper adaptation on the partially erupted teeth and low SaO_2 values, further studies in the field must be directed toward using reflectance oximetry and producing a monitor with probe specifically calibrated for the tooth
5. As modern endodontics is becoming influenced by novel biological, genetic and metabolic approaches toward new strategies for regeneration of dental pulp, the technology with which pulse oximeter works can be adapted for the true objective evaluation of the progress of regeneration, which could be a leap into the future of endodontics.

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