EVALUATION OF A CUSTOM MADE PULSE OXIMETER DENTAL PROBE IN DETECTING PULP VITALITY – A CLINICAL STUDY.

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Certificate

This is to certify that **Dr. S. Prabhakaran**, has done this dissertation titled ***"EVALUATION OF A CUSTOM MADE PULSE OXIMETER DENTAL PROBE IN DETECTING PULP VITALITY – A CLINICAL STUDY."*** under our direct guidance and supervision, in partial fulfillment of the regulations laid down by *THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY*, Chennai for the ***MASTER OF DENTAL SURGERY*** **(PEDODONTICS AND PREVENTIVE DENTISTRY)** degree examination.

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CONTENTS

INTRODUCTION

Robinson HGB (1963)[40] defined diagnosis in dentistry as 'the process whereby the data obtained from questioning, examining and testing are combined by the dentist to identify deviations from the normal'. An accurate and correct diagnosis is the basis for rational therapy and is the first step in adequate treatment. Millard HD (1963)[29] noted that an accurate and complete diagnosis can result from a thorough and systematic collection of all available information about a patient and the logical arrangement and subsequent study of this information. One of the important aspects of oral diagnosis is pulp vitality testing[8].

The pulp is a vascular connective tissue contained within the rigid pulp cavity. The prime function of the dental pulp is the formation of dentine of the tooth; and later the formation of reparative dentine in response to damage to the dentine. The blood supply to the pulp enters through the apical and accessory foramina via small thin-walled vessels, arterioles. They form a capillary network in the subodontoblastic layer and the capillaries drain into venules which run along side the arterioles and pass out through the apical foramen[5].

The pulp can be damaged due to a variety of causes. However, it is now considered that the most common cause of pulpal damage is probably the effect of bacteria and their toxins, which passes down dentinal tubules from carious lesions. Mechanical damage to the tooth may cause loss of tooth structure (enamel) resulting in the opening of thousands of dentinal tubules allowing the ingress of bacteria. Therefore it is necessary to establish as accurately as possible the state of the pulp in the diagnosis of dental pain and before embarking on operative procedures[8].

Pulp vitality is purely a function of vascular health. Hence a direct measurement of pulpal circulation is the only real measure of pulp vitality[3,8,24]. The current method of assessing pulp vitality includes thermal tests, electrical tests, test cavity and anesthetic tests[34]. These tests establish the presence of nerve pathways in the pulp and thus they do not assess vitality accurately.

These methods have limitations in providing accurate diagnosis and are difficult to administer or inconclusive when used in children[19,38].

Both electric and thermal pulp testing requires subjective responses from the patient, their use often leads to inaccurate results[19]. Children cannot always describe subjective symptoms or sensitivity to a stimulus[19]. False positives or false negatives occur if the dentist asks the child a leading question[6]. Furthermore, both thermal and electric pulp testing are perceived as unpleasant stimuli, which may result in behavioral or cooperation problems with the pediatric patients. As children adapt their behavior to avoid a painful stimulus, their ability to properly respond to pulp testing is limited[23,27].

Another problem with present pulp testing methods is that they only indirectly monitor pulp vitality by measuring neural responses and not circulation. A vital pulp with an intact vasculature may test non-vital if only its neural component is injured. This situation is encountered commonly in recently traumatized teeth[18]. On the other hand, pulp nerve fibers are more resistant to necrosis than vascular tissue, and thermal or electric testing of only pulp neural response may also result in false positive results if only the pulp vasculature is damaged[16].

For both electric and thermal testing to be effective, the pulp must have a sufficient number of mature neurons. However both primary and immature permanent teeth are not fully innervated with alpha myelinated axons, the neural components which are responsible for pulpal pain response[21]. Permanent teeth may not exhibit full alpha myelinated axon innervations until 4 – 5 years after eruption[13]. This reduced number of pain receptors makes them less responsive to stimuli and therefore more susceptible to false negative results from thermal or electric pulp testing[15,24]. Considering these limitations, present pulp testing methods cannot be considered reliable vitality tests for the pediatric patient[19].

Pulse oximetry is a completely objective test, requiring no subjective response from the patient, as it directly measures blood oxygen saturation levels. Pulse oximetry is based on placing arterial blood vessels between a light source and a detector. The light source diode emits both infra-red and red light, which is received by a photo detector diode. Blood pulsating through the vessels changes the light path, which modifies the amount of detected light. This determines the pulse rate. To determine oxygen saturation ($Sa0_2$), the pulse oximeter measures and compares amplitudes of the ratios of transmitted infra-red with red light. This ratio varies with relative fractions of oxygen saturated to unsaturated hemoglobin and is used to calculate $Sa0_2$. Skin, bone and venous blood do not interfere with measurements. These characteristics infer that pulse oximetry is also capable of evaluating the blood vasculature status within a tooth, and therefore pulp vitality[19].

Earlier pilot study by Schnettler J, Wallace J (1991)[44] indicated the efficacy of using pulse oximetry to test pulp vitality on mature permanent teeth. An in-vitro study by Noblett (1996)[34] on permanent tooth models, clearly demonstrated the strong correlation between pulse oximetry evaluation of pulp oxygen saturation and arterial blood gas analysis. Another study by A.K.Munshi (2002)[31] also showed that pulse oximetry is an effective objective method of evaluating dental pulp vitality especially in pediatric patients.

The purpose of this study is to design and develop a dental probe that adapts to the contour of incisors and to evaluate the potential of the pulse oximeter and new probe in detecting the vascular integrity of human teeth and to compare its effectiveness over the electrical testing method.

AIMS AND OBJECTIVES:

1. To design and develop a probe that adapts to the contour of the permanent central incisor.
2. To evaluate the potential of the newly developed probe and the hand held pulse oximeter in detecting the vascular integrity of human teeth.
3. To compare the newly developed probe and the hand held pulse oximeter assessment with electric pulp testing.

REVIEW OF LITERATURE

Bhaskar SN, Rappaport HM (1973)[3] clinically observed 25 anterior teeth that had been traumatized and did not respond to the conventional vitality tests. Examination of the pulp chambers revealed that all the teeth had vital pulps. Radiographs taken at various times after the trauma showed narrowing of root canals. Whereas the pulp tissue acquires its vitality from its blood supply, the nerves provide it only with sensitivity. Since the conventional vitality test establishes only the status of the nerve, the response can be negative and yet the pulp tissue may be vital. It is recommended that in traumatized teeth endodontic therapy should be delayed and the affected pulpal tissue considered vital. If apical radiolucent regions or fistulas develop, endodontic therapy can be instituted.

Millard HD (1973)[30] said that electric pulp tester is an important diagnostic aid for the evaluation of pulpal vitality. It is a safe clinical test that provides information when correlated with symptoms and clinical and radiographic findings. These testers deliver an electric stimulus to the tooth. When used correctly a properly functioning pulp tester will indicate whether there is vital nerve tissue in the tooth that is capable of reacting to the stimulus. A medium of high dielectric constant and water base such as toothpaste has been shown to increase the impulse transmitted to the pulp from the electrode of the pulp tester. The most important aspect of using the electric pulp tester is interpretation of the response of the patient in the light of findings from the history, radiographs and clinical examination and from the reaction of a control tooth.

Civjan S, Barone JJ, Vaccaro GJ (1973)[9] compared the output of three commercially available electric pulp testers and determined if the output has a relationship to threshold settings. Three pulp vitality testers included were Vitalometer, Vitapulp and Dentotest. Output voltage waveforms for each pulp tester were observed with an oscilloscope. The records of the waveforms of the three testers were used to determine peak voltage, voltage rise time, pulse duration, frequency, and root mean square output voltage. And to correlate the clinical response setting and output, three observations were made on each asymptomatic and radiographically normal maxillary anterior tooth of fourteen volunteer patients. The three electric pulp testers examined showed considerable variations in output characteristics. Clinical threshold settings of the three instruments could not be correlated on the basis of peak voltage, root mean square voltage, or power outputs determined by use of simulated load impedance.

Matthews B, Searle BN, Adams D, Linden R (1974)[26] carried out experiments to determine whether the results given by an electric pulp tester can be used as a reliable indication of the vitality of a tooth. The thresholds of thirty teeth were determined with two pulp testers, one a commercially available instrument with no current control, and the other a specially made, constant current stimulator. The pulps of the teeth were then examined histologically. The commercially available instrument was capable of exciting periodontal nerves and gave false positive responses. On the other hand, the constant current instrument was incapable of evoking a response from some vital teeth using stimuli, which were sub-threshold for periodontal nerves. There was no correlation between the thresholds of the vital teeth and the pathological state of their pulps.

Michaelson RE, Seidberg BH, James Guttuso (1975)[28] designed an in-vivo study to compare four interface media (Crest and Sensodyne toothpaste, EKG paste and water) with Sensitron electric pulp tester to determine whether the amount of current needed to elicit a response varies with these materials. Each material was tested on the facial and lingual surface of anterior teeth and dry contact was used as control. Clinical results showed no appreciable difference between the material used provided they were water and petroleum based. Facial and lingual readings were the same in about half the test and lingual readings were slightly lower than facial readings in 40% of the test.

Fulling HJ, Andreasen JO (1976)[15] studied the influence of maturation status and tooth type of permanent teeth upon electrometric and thermal pulp testing. The threshold values of developing teeth were determined for two commonly used electrometric pulp testers (Siemens Sirotest and Bofors Pulp Tester) and a new thermal test based on carbon dioxide snow (Odontotest). The teeth examined were divided into 7 stages according to maturation status. This study showed that teeth in stages 3-5, i.e. until completion of root formation, show an increased electrometric threshold value. The Siemens tester appeared to be equal to the Bofors tester with regard to reliability. The Odontotest was the most reliable method examined, giving a consistent positive response in all examined teeth.

Stark MM, Kempler D, Pelzner RB, Rosenfeld J, Leung RL, Mintatos S (1977)[45] developed a new electric pulp-testing system, the Testark, in order to assess the potential of a different way of testing pulp sensitivity, in comparison with a commercially available pulp tester. The study consisted of application of three different desensitizing agents (sodium fluoride, test product. 'A', and test product 'B') to the cervical areas of hypersensitive teeth. The results were recorded with both the Testark and the conventional pulp tester simultaneously, and the sodium fluoride and test product 'B' proved to yield a beneficial effect by desensitizing the teeth after a single application. The level of desensitization with these agents was higher than the level obtained with the test product 'A' paste, which was utilized daily for 14 days. The results obtained with the conventional pulp tester differed by way of interpretation from those obtained with the Testark system. The Testark system proved to be easy to use and highly accurate in the data readings because of its high resolution. The Testark system was found to be more dependable than the commercial pulp tester, since it reduced the subjective errors, which are inevitable when a commercial pulp tester is used.

Klein H (1978)[24] evaluated the pulp response to an electric pulp stimulator in the developing permanent anterior dentition during different stages of tooth development. Ninety-three children (51-boys, 42-girls) between the ages 6 -11 years were selected. The responses of 631 permanent anterior teeth were tested twice with a time interval of one week by means of Burton Vitalometer. Four categories of apex formation were recorded: completely open, two-thirds open, one-third open and closed. There were no statistically significant differences between the responses of the first and second tests of same tooth. The results showed that high percentage (89.2%) of the teeth with completely open apices did not respond to electric pulp stimulation, whereas the positive responds increased during the stages of root development. Some tooth with closed apices also did not show any response. There was no difference in responses between the teeth of the right and left sides as long as the roots of the tested teeth were in the same stages of development.

Cooley RL, Robison SF (1980)[10] evaluated the variables associated with electric pulp testing. A modern electronic pulp tester was evaluated in both the laboratory and clinical situations. Different electrode media were tested and compared to results obtained without any electrode media. Contact pads were also evaluated and found to add another variable to electric pulp testing. Several technique variables were introduced and found to have a significant effect on transmission of the stimulus to the tooth.

Jacobson JJ (1984)[20] studied the probe placement during electric pulp-testing procedures. They evaluated in a laboratory setting using thirty-one extracted teeth, an oscilloscope, and a new electric pulp tester (Digital Analytical Pulp Tester). Among the various sites of the electrode placement, the lowest resistance occurred on the occlusal two-thirds of the labial or buccal surfaces of maxillary incisors and premolars. More specifically, the middle-third of the incisors and the occlusal-third of the premolars were shown to have the least resistance. The electrode placement area on the crown where the pulp nerve is first excited to threshold must be identified to avoid false-positive stimulation of surrounding periodontal nerves. This will decrease nerve damage and ensure the patient's cooperation and acceptance.

Fuss Z, Rickoff B, Trowbridge H, Bender IB (1985)[16] evaluated the efficacy of various pulp testing agents to evoke a sensory response when applied to intact human teeth; electric pulp tester, ethyl chloride, dichlorodifluoromethane and carbon dioxide snow. The cold tests were conducted by applying each of the agents to the buccal surface of 77 premolars in patients ranging in age from 9 to 34 years. The response to stimulation was recorded as either negative or positive. The tests were repeated in-vitro on extracted premolars maintained at 34º C. During each test the temperature change in the subjacent region of the pulpodental junction was determined by means of a Thermister probe. Results of in-vivo test showed that electric pulp tester, dichlorodifluoromethane and carbon dioxide snow produced the greatest percent of positive responses (94.8, 98.7 and 97.4 respectively) followed by ethyl chloride (53.2) and ice (32.5). These values were analyzed by the chi-square method and found to be statistically significantly different ($p < 0.01$). A test period of 15 seconds on the extracted teeth produced average temperature decreases in the region of the pulpodental junction as follows: ice- 4.1ºC, ethyl chloride- 4ºC, dichlorodifluoromethane - 6.9 ºC and carbon dioxide snow- 8.6º C. On the basis of these results it is concluded that electric pulp tester, dichlorodifluoromethane and carbon dioxide snow are more effective vitality testing agents than ice and ethyl chloride.

Kolbinson DA, Teplitsky PE (1988)[25] studied the use of electric pulp testing with the operator wearing examination gloves. In this study, 15 female and 15 male subjects had two different clinically sound teeth tested with an Analytic Technology digital electric pulp tester, both with and without latex examination gloves being worn by the operator. Statistically significant differences between EPT results for the same teeth with the operator's hands being gloved and ungloved were noted. However, the mean differences in EPT results were small and were thought to be diagnostically insignificant for clinical situations. As long as the patient "completes the circuit" by also holding the metallic handle of the electric pulp tester's probe, dentists can easily, reliably, and accurately use the EPT while wearing examination gloves.

Bender IB, Landau MA, Fonsecca S, Trowbridge HO (1989)[2] studied the optimum placement-site of the electrode in electric pulp testing of the 12 anterior teeth. 2,387 recordings of 12 anterior teeth in 53 patients indicate that the incisal edge is the optimal placement-site for the electric pulp tester to determine the lowest response threshold. The results show significant individual variations in the lowest threshold responses of the cervical-third, middle-third, incisal one-third, and incisal edge sites on a tooth, with a confidence level of 99%, according to the analysis of variance. The maxillary teeth gave a higher response threshold than the mandibular teeth and different types of teeth (canines and incisors) had statistically significant different response thresholds. The application of the electric pulp tester to the incisal-edge region with exposed dentin produced the most significant decrease in the threshold response.

Schmitt JM, Webber RL, Walker EC (1991)[43] explored the feasibility of employing photoplethysmography and pulse oximetry to assess the status of the blood circulation in the dental pulp. A simple photometer that measures diffuse light transmission at 575nm was built to record tooth plethysmograms, and the ability to distinguish vital from surgically devitalized teeth of a dog using plethysmography was demonstrated. As an extension of the photoplethysmo-graphic technique, red-infrared pulse oximetry applied to the measurement of the oxygen saturation of blood in the pulp was also examined using an in vitro test setup. Results suggest that the measurement of relative oxygen saturation changes is feasible, but standard dual-wavelength pulse oximetry does not enable determination of oxygen saturation independent of tooth geometry and sensor placement.

Schnettler JM, Wallace JA (1991)[44] investigated the potential of the pulse oximeter to detect vascular integrity within the human tooth. Forty-nine young adults were evaluated for the vitality of their maxillary central incisors utilizing thermal, electrical, and oximetric techniques. The pulse oximeter was found to indicate a pulse rate and oxygen saturation reading for the vital teeth and no readings for the teeth previously endodontically treated. The accuracy of this diagnostic method supports the need for additional study in the use of the pulse oximeter to interpret the pathological processes of the pulp.

Dal Santo FB, Throckmorton GS, Ellis E 3rd (1992)[11] evaluated the reproducibility of data from a hand-held digital pulp tester used on teeth and oral soft tissue. The reproducibility of these readings is important if the instrument is to be used for determining differences in sensitivity. Twenty human subjects (16 male) were studied. One incisor, one premolar, one molar tooth with small or no restorations, and two gingival soft tissue positions from each upper and lower arch of each subject were stimulated with the Analytic Technology Vitality Scanner. This procedure was repeated twice with a 5-minute rest between each trial, for a total of three trials. Each subject was then seen again after a period of at least 3 days, at which time the trials were repeated. The collected data were grouped by trial, tooth position, and day. Paired t test analysis of both the absolute difference between any two trials on the same day and the average of the absolute differences between corresponding trials on days 1 and 2 showed no statistically significant differences (p greater than 0.05). Accommodation to the stimulus was evaluated by examining differences in the mean values between the three same-day trials. The Analytic Technology Vitality Scanner was found to be reproducible both for consecutive same-day trials and for corresponding trials on different days. No same-day trends in meter readings were noted.

Nissan R, Trope M, Zhang CD, Chance B (1992)[33] determined the feasibility of using dual wavelength spectrophotometry to identify teeth with pulp chambers that are either empty, filled with fixed pulp tissue, or filled with oxygenated blood. In phase I of the experiment, a human third molar was prepared so that its pulp space could be filled with oxygenated blood and later emptied. In phase II, the lower jaw of a beagle dog was removed and placed in formalin, thereby fixing the pulps of the teeth. The pulp of the right canine was removed via an apical approach, and attachments were placed in a similar position to those on the human tooth, to allow filling and emptying of the pulp space. Cavit was placed over the exposed fixed pulp in the left canine. Ten readings, which were separated by light source and detector removal and replacement, were taken of the right canine pulp space when it was empty or filled with oxygenated blood or the left canine pulp space when it was filled with fixed tissue. Distinct and reproducible changes were measured for pulp spaces filled with air, tissue, or oxygenated blood. In phase III, simulated pulp testing on a dog tooth model was performed. Blood was introduced into the root canal space; the chamber was rinsed with water and replaced with air, according to a predetermined code. Spectrophotometer readings were recorded. The identification of pulpal contents was correctly determined in all 20 of the predetermined conditions. These findings indicated that continuous wave spectropho tometry might prove to be a useful pulp testing method.

Pantera EA Jr, Anderson RW, Pantera CT (1992)[36] evaluated the effectiveness of the use of dental instruments for bridging during electric pulp testing. One hundred seventeen vital teeth in 20 volunteers were tested. Ten endodontically treated teeth functioned as controls. Following appropriate isolation and asepsis technique, baseline recordings of the threshold response with the electric pulp tester were taken. With the use of dental explorers and endodontic files to bridge between the probe tip and the tooth surface, recordings were made of the threshold responses. Their findings indicated that electrically conductive dental instruments could be reliably used as bridging instruments with the electric pulp tester.

Reynolds KJ, Moyle JT, Gale LB, Sykes MK, Hahn CE (1992)[40] developed an in-vitro system capable of testing the accuracy and reproducibility of pulse oximeter readings. The pulse oximeter probe receives signals through a pulsating blood cuvette. Using the final design (or 'model finger'), a comparison is made between readings from a Datex Satlite pulse oximeter (SpO_2) and saturation values obtained by use of a multi-wavelength bench oximeter (SaO_2). Linear regression analysis of the data gives $SpO_2 = 0.88\ SaO_2 + 11.2$ ($r = 0.979$, $p < 0.001$).

Pantera EA Jr, Anderson RW, Pantera CT (1993)[37] conducted a study to determine if the sequence and interval between electric pulp testing and cold vitality testing with dichlorodifluoromethane affects the reliability of pulpal diagnostic testing. Sixty vital teeth in 15 volunteers were tested. Ten endodontically treated teeth were used as negative controls. After isolation and asepsis techniques, baseline threshold responses from a digital electric pulp tester were recorded from the maxillary incisors. A dichlorodifluoromethane-saturated cotton pellet was applied to teeth 8, 9, and 10. Electric pulp testing was repeated at 30-s, 1-min, and 2-min intervals on all test teeth after the cold test. The level of responses were recorded and statistically analyzed. The results indicated that electric pulp testing is not adversely affected by the use of dichlorodifluoromethane.

Peters DD, Baumgartner JC, Lorton L (1994)[38] evaluated the positive and negative responses to cold and electrical pulp tests. The positive and negative responses of 1488 teeth in 60 patients were evaluated. Three subgroups of known pulpless or pulpally diseased teeth (teeth receiving root canal therapy, teeth with root canal fillings, or teeth with confirmed associated apical radiolucencies) were identified and their responses evaluated separately. Testing was performed on two tooth surfaces, the facioocclusal and faciocervical, and on all restorations. The gingival tissue of each patient also was tested using both electrical tests. Their primary findings were: (a) teeth not responding to cold and either not responding or responding at readings greater than the tissue response to electrical pulp testers had a high probability of being in the known pulpless or pulpally diseased subgroups; (b) the only false positive responses to cold in the three subgroups were in multirooted teeth with probable vital tissue remaining in at least one canal; and (c) the false positive responses to electrical pulp testers that responded at levels higher than the patient's tissue response were considered to be negative responses, the difference in false positives between cold and electrical was not statistically significant ($p = 0.07$).

Asfour MA, Millar BJ, Smith PB (1996)[1] assessed the reliability of children's responses to pulp testing of deciduous teeth. The maxillary canine was chosen as the test tooth. One hundred children aged 7-10 years were selected who had at least one non-carious maxillary canine with an intact root showing only early radiographic signs of resorption. Using a minimization sampling technique, the children were allocated to one of two groups, for pulp testing with ethyl chloride (EC) or with an electric pulp tester (EPT). True and sham tests for both pulp testing methods were applied. The tests were repeated following an application of 5% lignocaine paste to the gingival margin around the tooth to prevent gingival detection of the stimulus. Children were asked to record their responses to each of the four tests on a visual analogue scale (VAS) of 1-10. Significantly higher mean scores were obtained with true tests than with sham tests, for both ethyl chloride and electric pulp tester. The application of lignocaine to the gingival margin did not significantly affect the responses to either ethyl chloride or electric pulp tester. They concluded that pulp testing of intact maxillary deciduous canines with no or only early signs of radiographic root resorption, using ethyl chloride or electric pulp tester, results in reliable responses in 7-10-year-olds, suggesting that pulp testing is valid in the deciduous dentition. The visual analogue scale was a useful tool for the evaluation of the children's responses.

Kahan RS, Gulabivala K, Snook M, Setchell DJ (1996)[22] evaluated the customized probe for pulp vitality testing using pulse oximeter. In this study, an optimized pulse oximeter probe for teeth was designed, built and tested using the Biox 3740 Oximeter (Ohmeda, Louisville, CO). Following preliminary in vitro tests, the probe was tested clinically. Pulse waveforms from maxillary and mandibular anterior teeth were noted. Simultaneous readings from the subject’s finger were used as controls. Pulse wave readings from the teeth were found to be synchronous with the finger probe, but not consistently. It was easier to maintain continuous readings from mandibular incisors than from maxillary incisors. The average percentage synchronization with the pulse was 28.95% for maxillary incisors and 50.28% for mandibular incisors. This difference was significant ($p = 0.05$). The overall accuracy of the commercial instrument was disappointing, and in its present form it was not considered to have clinical value.

Noblett WC, Wilcox LR, Scamman F, Johnson WT, Diaz-Arnold A (1996)[34] evaluated pulse oximetry as a potential method of determining pulp vitality. An in-vitro model of pulpal circulation was fabricated to test the design for a dental pulse oximetry sensor. Blood samples equilibrated with hypoxic gas mixtures were circulated through the model by a peristaltic pump. A pulse was simulated by introduction of gas bubbles into the blood circulation. Pulse oximeter readings for saturation were recorded and compared with blood gas analysis results. Statistical analysis revealed no difference between pulse oximetry and blood gas analysis with a highly significant correlation coefficient.

Oikarinen K, Kopola H, Makiniemi M, Herrala E (1996)[35] described a new system in which optical reflectance was used to test the pulse and vitality of oral mucosa or dental pulp. Radiations at red (660 nm) and near infra-red (850 nm) wavelengths are directed through a thin probe. The beam is directed into tissue and reflected back. Plethysmography was used to measure the pulse rate from the right forefinger. Reflected radiation is related to plethysmogram using a computer. Preliminary findings relating to the lips and gingiva in nine healthy volunteers were promising. Preliminary tests showed that vital and nonvital pulps reflected the radiation differently. Pulpal pulse did not always correspond to plethysmogram from the right forefinger.

Goho C (1999)[19] evaluated the vitality of primary and immature permanent teeth using pulse oximetry. This study explored the use of a modified pulse oximetry ear probe to assess pulpal vascular oxygen saturation in primary and immature permanent teeth. Pulse oximetry readily differentiated between known vital and nonvital teeth. Vital teeth consistently provided SaO_2 values that were lower than the values recorded on the patient’s fingers. Pulse oximetry is already an objective, atraumatic clinical alternative to the present electrical and thermal methods of assessing pulp vitality in children's teeth.

Cave SG, Freer TJ, Podlich HM (2002)[7] studied the pulpal response in the orthodontic patient. Thirty-three subjects commencing fixed orthodontic treatment and another 15 subjects not undergoing orthodontic treatment were studied. Cold and electrical stimuli were applied to the maxillary incisor teeth prior to treatment, after the placement of fixed appliances and at regular intervals for both groups for up to 252 days. At baseline, response thresholds to electric testing were typically higher for orthodontic subjects, particularly for the lateral incisors. For the non-orthodontic group, the response threshold over the 252 days was relatively constant. For the orthodontic group, application of force immediately increased the response threshold to electric pulp testing, which peaked after two months. By day 252, response mean for lateral incisors still remained elevated. Responses to thermal testing were more consistent and reliable. They conclude that dental practitioners should interpret responses to electric pulp testing cautiously in orthodontic patients.

Munshi AK, Hegde AM, Radhakrishnan S (2002)[31] used pulse oximeter as a diagnostic instrument in pulpal vitality testing. One hundred children with normal maxillary central and lateral incisors were subjected to vitality tests each by electrical and pulse oximetry. Ten known non-vital anterior teeth with complete endodontic fillings were tested and used as control. The systemic oxygen saturation values measured on the index finger of the patient served as the control for the comparison of the oxygen saturation values measured on the teeth. The SaO_2 values obtained on the teeth were correlated with the electrical test readings. The correlation between the SaO_2 readings and electrical testing readings were found to be negative i.e. as the values of the electrical pulp testing reading increased, the SaO_2 values decreased. Since a reproducible SaO_2 level is obtainable on the vital teeth, pulse oximetry has immediate clinical value in providing base line vitality data for the traumatized teeth.

Nam KC, Ahn SH, Cho JH, Kim DW, Lee SJ (2005)[32] measured the excessive electrical stimulus time during pulp testing via electromyography (EMG) in the anterior belly of the digastric muscle, voice and finger movement, and determined whether excessive stimulus time could be attenuated by a specially designed automatic circuit breaker on the basis of the EMG signal. The signals from three human responses (EMG, finger and voice), induced by the Digitest (Parkell Inc., Farmingdale, NY, USA) electric pulp tester, were captured using a MP100 (Biopac System Inc., Goleta, CA, USA) and recorded into a personal computer. The excessive stimulus time from activation to the end of electrical stimulation was calculated for each of these three responses. The automatic circuit breaker was designed to disconnect the electrical output of the electric pulp testing (EPT) unit immediately after detecting the preset EMG level (100 mV). Each of the right central incisors and first premolars of 23 healthy individuals (16 males and seven females) was tested to see whether there was a difference in tooth type or gender. This was analyzed by Wilcoxon signed rank test (nonparametric paired t-test) and Mann-Whitney test (nonparametric independent t-test), respectively. Amongst three human responses, the electrical onset occurred in the order of EMG, finger and voice. Excessive stimulus time was 347.8 +/- 78.3 ms when observed by the EMG, 264.9 +/- 63.9 ms when observed by finger span and 229.4 +/- 41.8 ms when observed by the voice, which were all found to be significantly different ($P < 0.05$). When the automatic circuit breaker was used, the excessive stimulus time was 61.0 ms, which was 286.8 ms shorter than that measured from EMG onset when using the conventional EPT. The authors concluded that when the automatic circuit breaker was used, excessive stimulus time on the basis of EMG was attenuated on average by 286.8 ms.

MATERIALS AND METHODS

This study was carried out in the Department of Pedodontics and Preventive Dentistry, Meenakshi Ammal Dental College, in association with LUB DUB Medical Technologies Pvt. Ltd., Chennai.

FABRICATION OF CUSTOM MADE PULSE OXIMETER PROBE FOR THE TOOTH

I. Designing of custom made probe.

Alginate impressions of the upper and lower arches of primary and permanent dentition were taken and a die-stone model was prepared. These models were given to a biomedical engineer (LUB DUB Medical Technologies Pvt. Ltd., Chennai) to be used as a template for designing the custom made pulse oximeter probe. The mesiodistal width and the vertical height of the permanent central incisors were measured with the help of a vernier caliper from the cast given. Measurements of the labial and palatal curvature of the incisors from the gingiva to the incisal edge were taken using Radius Gauge. These measurements were used to draw the three dimensional view of the tooth structure using PRO-Engineering 3D software. With this tooth design a well adapted custom made pulse oximeter probe was drawn over it using the same software. This probe is a type of clip with two halves which will be stabilized with the help of a hinge pin and low tension spring.

II. Preparation of die.

The finalized three dimensional probe design was then converted to a two dimensional AUTO CAD design (Fig.1), which is used for machining the mould. An HDS iron cube (Fig.2) was used for the preparation of die. In this iron cube the probe design was prepared by machine cutting (Fig.3). Only one die was used for the probe design as the two halves of the probe clip are mirror images. This die was prepared with the help of a die manufacturer ENTECH Engineering, Chennai.

III. Preparation of probe clip.

The material used to prepare the probe was made of polypropylene, a bio-compatible material. Polypropylene pellets were heated to a temperature of 180^{o}C and it was injected into the die and half the probe was obtained. Similarly the other half was also prepared in the factory of LUB DUB Medical Technologies Pvt. Ltd., Chennai.

IV. Mounting of spring.

The two halves (Fig.4) of the new dental probe were mounted together with a hinge pin and low tension spring (Fig.5); both made of stainless steel, with the help of spring manufacturer VIKING Springs Ltd., Chennai. The new dental probe (Fig.6) was then placed on the extracted tooth to check for its stability.

V. Addition of sensors.

The probe was then loaded with LED'S and photo sensor (Fig.7) at LUB DUB factory, and was wired to the plug unit which can be connected to the pulse oximeter equipment (Fig.8). The pulse oximeter equipment used was a NONIN hand held pulse oximeter. The new dental probe and the pulse oximeter were tested for its reliability with standard testing equipment OXITEST $^{\textit{Plus}\ 7}$ (Fig.9) (Pulse Oximeter Tester, Datrend Systems. Inc.) owned by LUB DUB Technologies.

TESTING OF THE CUSTOM MADE PULSE OXIMETER PROBE ON HUMAN SUBJECTS

I. Sample selection.

Informed consent forms were handed over to about 242 children (Fig.10) in classes 6 – 9 (aged 9 -16 years) from Arulmigu Meenakshi Amman Matriculation Higher Secondary School, Chennai, to obtain their parents consent to participate in the study. Of the 242 students, 207 students returned the consent form with their parents consent. The students were then transferred to the department by the college bus (Fig.10). Details of each student were then entered on formatted evaluation form. Details such as name, age, sex and address were entered. Past medical and dental history were also recorded.

II. Selection criteria.

The criteria with which the subjects were included in the study were:

1. Fully erupted central incisors.
2. No previous history of trauma.
3. Teeth with no restorations.
4. Radiographic apex closure.
5. No periapical lesion.

Intra oral periapical radiographs of the upper central incisors of all the students were taken. Intra oral examination was carried out for each of the students and their radiographs were evaluated. Based on intra-oral examination and radiographic evaluation 10 students were found to possess endodontically treated tooth. Among the remaining 197 students 22 were excluded due to various reasons such as restoration or previous history of trauma or open apex.

III. Procedure.

The study population now consisted of 175 students and 10 students with endodontic filling served as controls. All the students were subjected to oral prophylaxis. The 175 subjects of the study group were tested for vitality of one of their maxillary central incisors using pulse oximetry and electric pulp tester. The 10 endodontically treated teeth were also tested the same way to confirm the pulse oximeter's evaluation of pulp vascularity.

The teeth were isolated with cotton rolls to avoid saliva contamination. The new dental probe was placed on the erupted crown so that light would travel from the facial to the lingual through the middle of the crown (Fig.12). The probe was positioned to create a light axis that was perpendicular to the axis of the erupted crown. The values were recorded on the evaluation form after 1 minute of monitoring each tooth. The patient's oxygen saturation reading from the index finger (Fig.13) was also recorded and then the same tooth was tested with electric pulp tester. The tooth was air dried and tooth paste was applied on the middle of the crown on the labial aspect which served as a conducting medium. The electric pulp tester was then placed on the tooth with zero reading (Fig.14). The value was slowly increased for every 15 seconds (Fig.15) and recorded when the patient responds to the electric stimuli (Fig.16). This procedure was carried without gloves so as to close the circuit of the electric pulp tester.

Pulse oximeter reading from the patients' fingers served as the control sample for comparison of pulp oxygen saturation values with the patients' systemic oxygen saturation values. The testing equipment consisted of the newly developed dental probe, NONIN hand held pulse oximeter and Parkell electric pulp tester. The recorded oxygen saturation and electric pulp tester values were tabulated and analyzed using Pearson's Correlation analysis to evaluate the relationship between the finger and tooth pulse oximeter readings.

ARMAMENTARIUM (Fig. 11)

Mouth mirror

Explorer

Tweezer

Surgical Mask

Surgical Gloves

New Dental Probe

NONIN Pulse Oximeter

Cotton rolls

High- Volume Evacuator

Saliva Ejector

Tooth Paste

Plastic Instrument

Three-Way Syringe

PARKELL Electric Pulp Tester

Evaluation Form

PULP VITALITY – EVALUATION FORM

NAME:

AGE:

SEX:

ADDRESS:

PAST MEDICAL HISTORY:

PAST DENTAL HISTORY:

TOOTH EVALUATED:

RADIOGRAPHIC EVALUATION:

EPT RESPONSE:

OXYGEN SATURATION – TOOTH:

OXYGEN SATURATION – FINGER:

PULSE RATE:

1. Finger - **2. Tooth –**

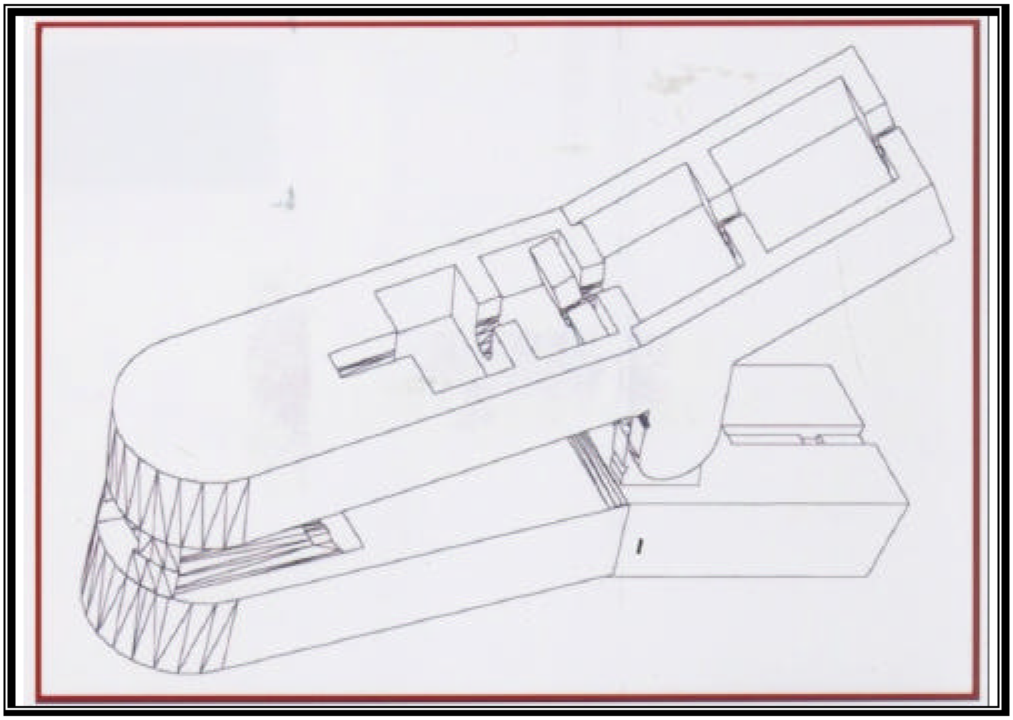

Fig 1: AUTO CAD Design of the dental probe clip.

Fig 2. HDS iron cube used for Die preparation.

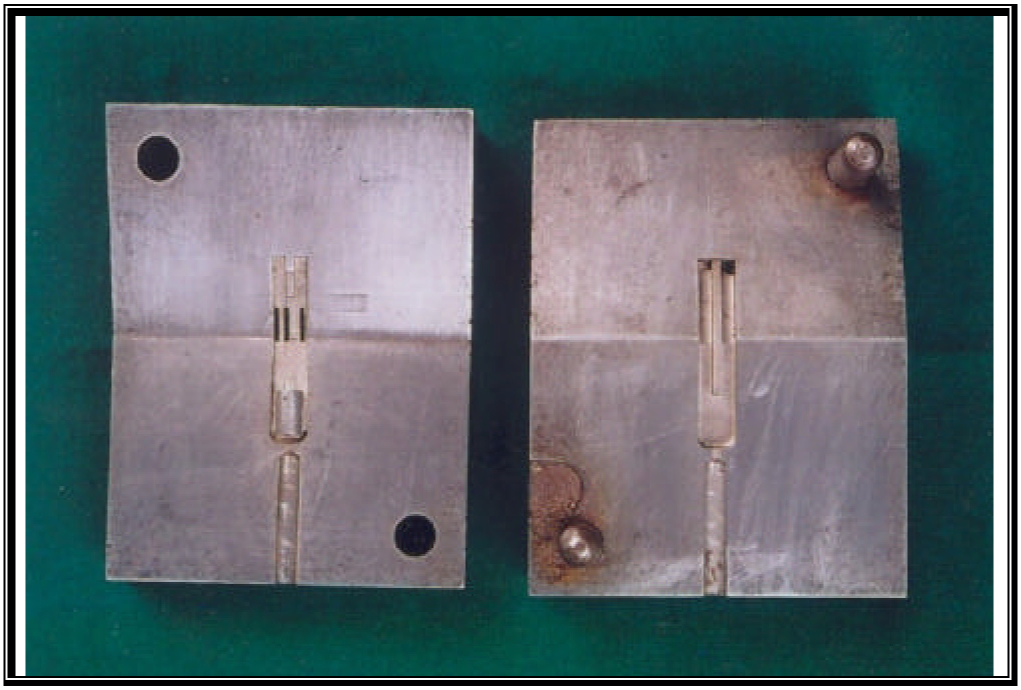

Fig 3. Prepared Die of the new dental probe clip.

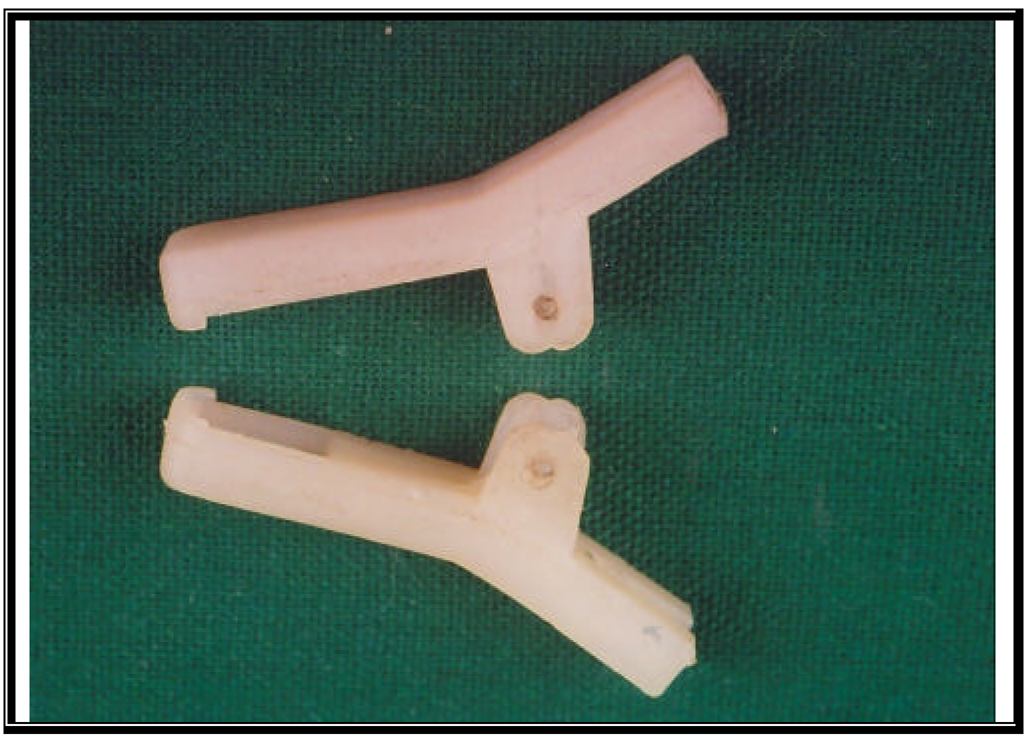

Fig 4. Two halves of the new dental probe clip.

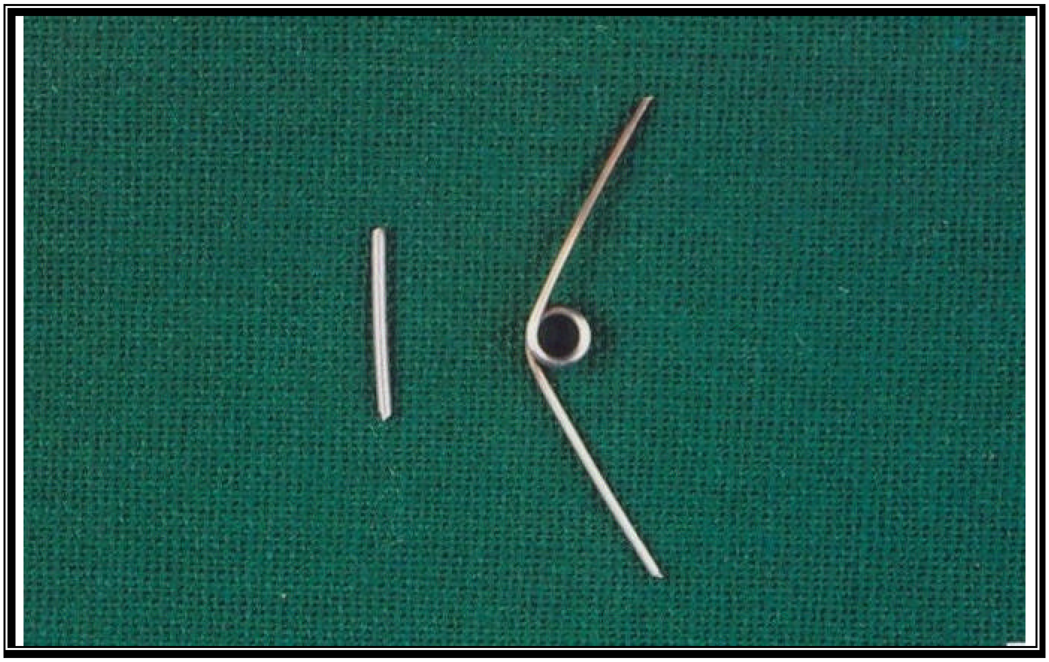

Fig 5. Hinge pin and low tension spring.

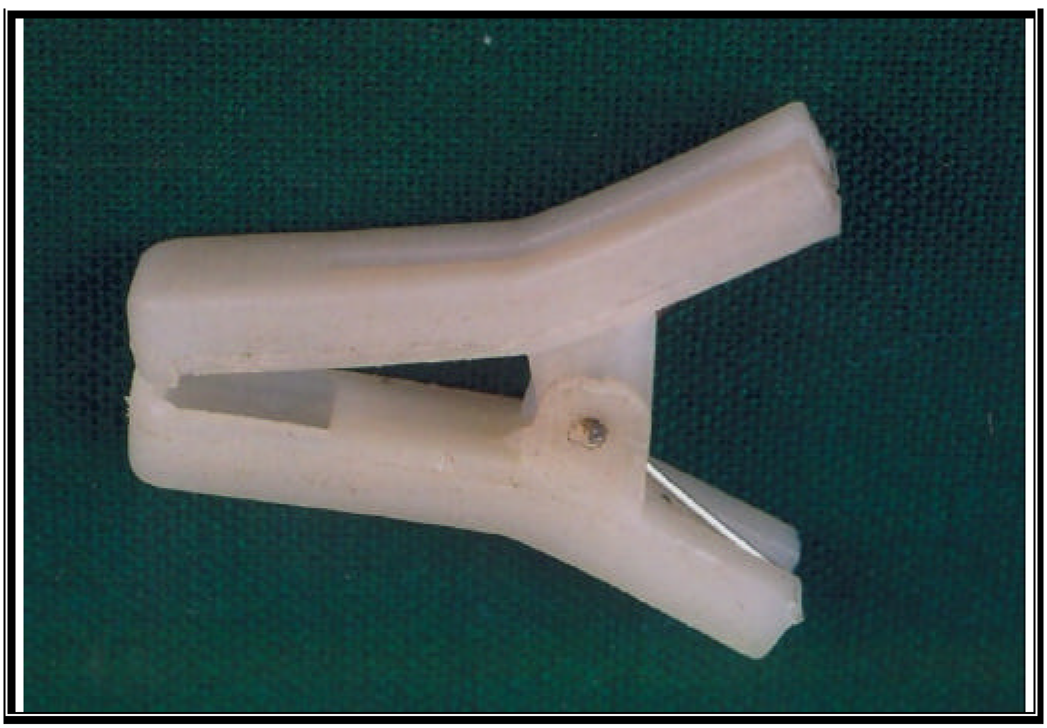

Fig 6. The new dental probe clip.

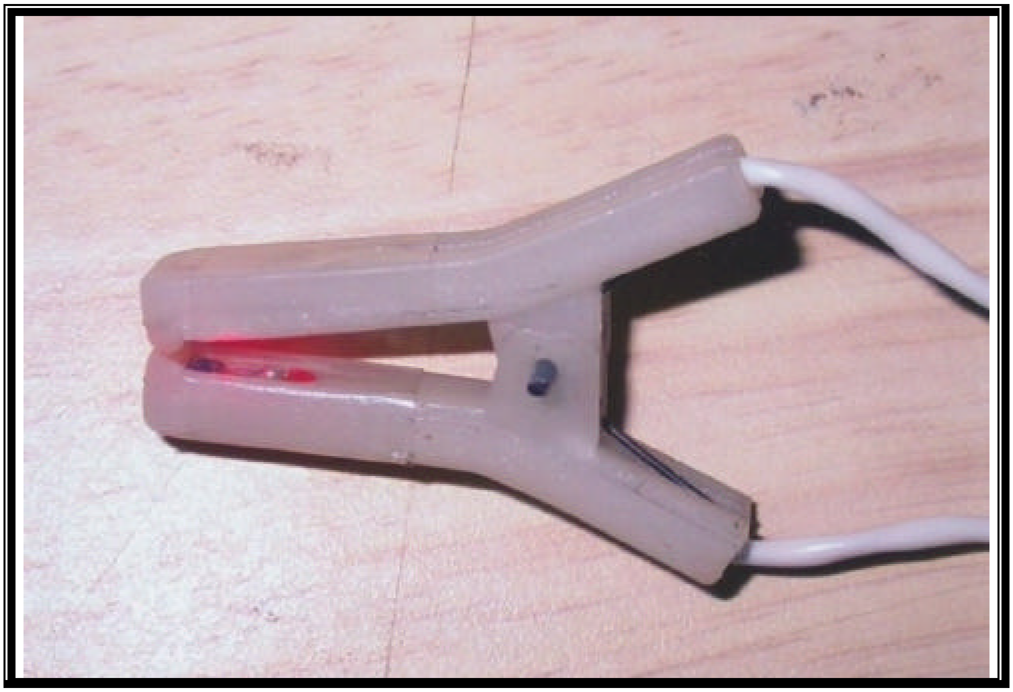

Fig 7. The new dental probe with sensors placed

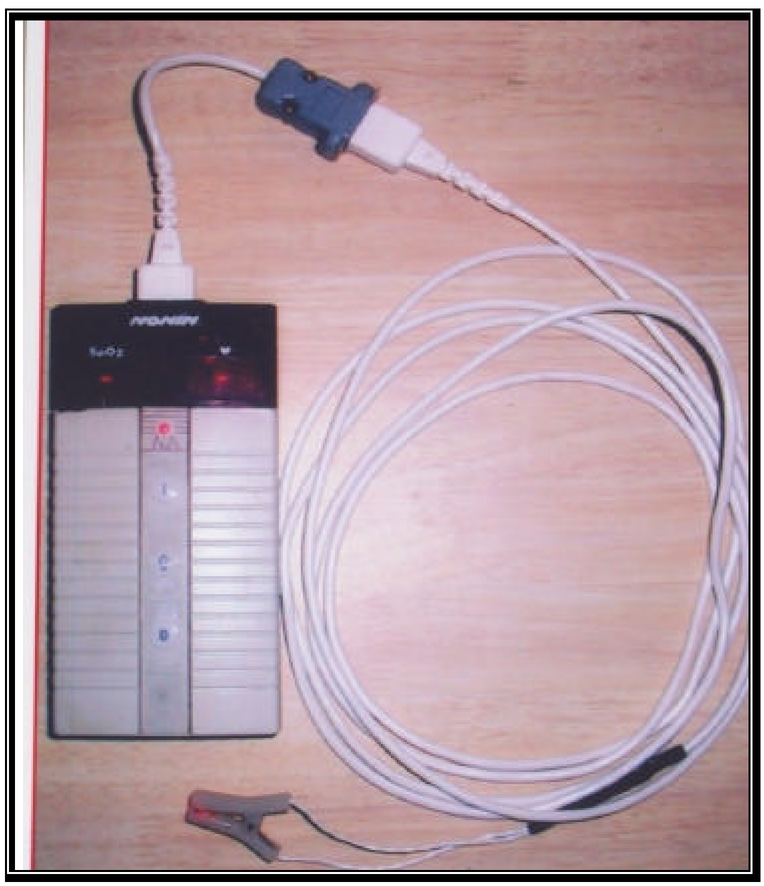

Fig 8. The NONIN pluse oximeter and the new dental probe.

Fig 9. OXITEST plus 7 pulse oximeter tester.

Fig 10. Part of the study subjects

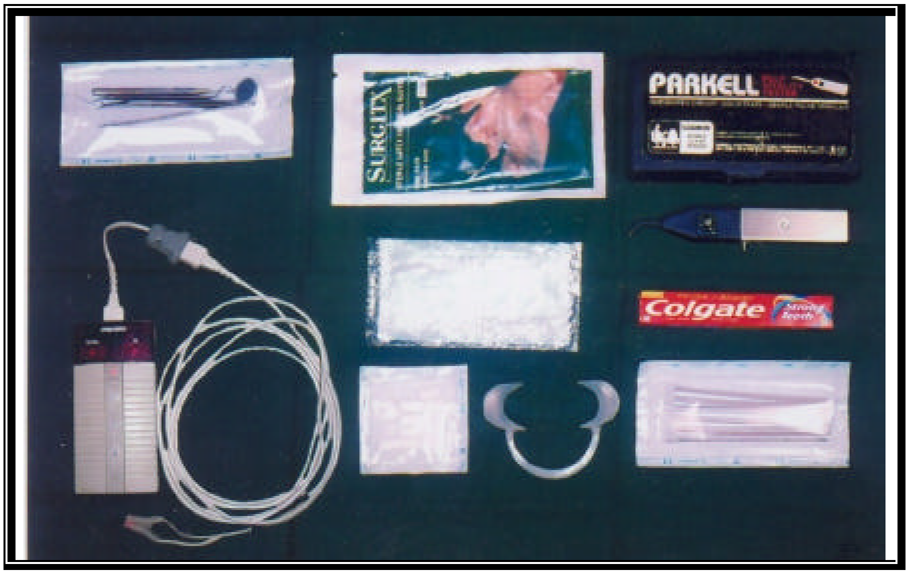

Fig11.Armamentarium

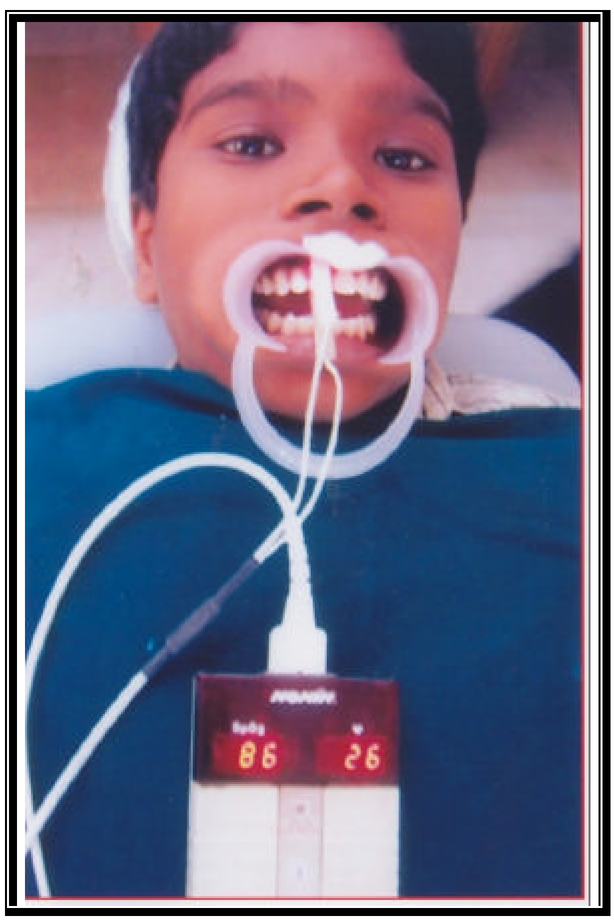

Fig 12. Oxygen saturation values from tooth being recorded

Fig 13. Oxygen saturation values from finger being recorded

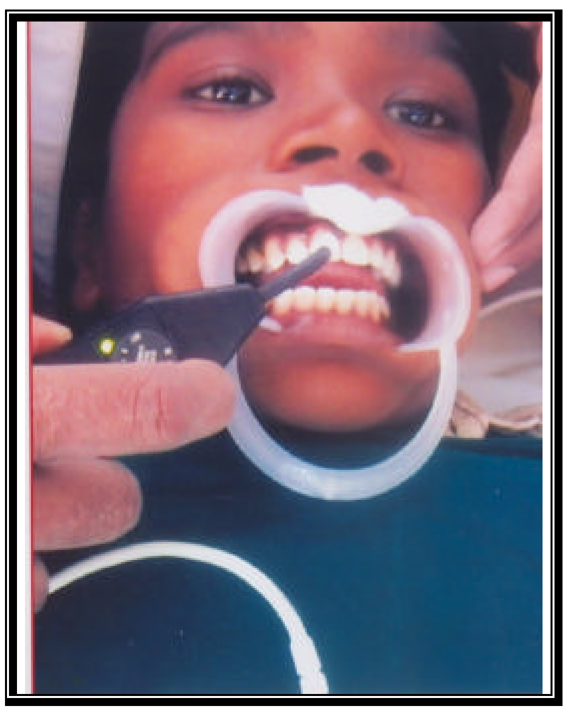

Fig 14. Electric pulp testing with zero value.

Fig 15. Electric pulp testing with value being increased.

Fig 16. Patient's Response to Electric pulp testing.

RESULTS

Table 1: Distribution Of Subjects.

Total No. of Subjects Examined	Excluded	Study Group	Control Group
207	22	175	10

Table 1 shows the distribution of samples selected for this study. Twenty two subjects were excluded as they do not fulfill the inclusion criteria. The number of subjects in the study group and control group were 175 and 10 respectively.

Table 2: Age And Sex Wise Distribution Of Study Group.

S. No	Age	Boys		Girls	
		Age	Mean Age	Age	Mean Age
1	9Years	1	12.82	-	12.72
2 3	10 Years 11 Years	- 18		- 11	
4	12 Years	28		13	
5	13 Years	29		26	
6	14 Years	20		13	
7	15 Years	13		2	
8	16 Years	1		-	
TOTAL		110		65	

Table 2 shows the age and sex wise distribution of the subjects in study group. The study group age were ranging from nine to sixteen years. The total numbers of boys were 110 and girls were 65. The mean ages of boys were 12.82 years and girls were 12.72years.

Table 3: Mean Oxygen Saturation Of Study And Control Group For Both Finger And Tooth.

Group	Sample size	Tooth		Finger	
		Mean	S.D	Mean	S.D
Study Group	175	83.6571	6.8437	97.0114	2.9556
Control Group	10	-	-	98.5	0.5270

Table 3 shows Mean and SD values of the oxygen saturation of study and control group for both finger and tooth. The oxygen saturation values for tooth and finger of the study group were 83.66 ± 6.84 and 97.01 ± 2.96, where as the oxygen saturation values of control group finger was about 98.50 ± 0.52. There was a statistically significant difference between mean of the tooth and finger of the study group ($p<0.05$).

Table 4: Mean Electric Pulp Tester Values Of Study And Control Groups.

Group	Sample Size	EPT values	
		Mean	S.D
Study Group	175	2.2914	0.8514
Control Group	10	No Response	No Response

Table 4 shows the Mean and SD values of the Electric Pulp Tester for the study and control group. The study group value was about 2.29 ± 0.85, where as for the control group there was no response.

Table 5: Comparison Of Oxygen Saturation Of Tooth And Electric Pulp Testing

	Pearson Correlation	***P* value ***
SaO_2 Tooth vs EPT	$r = 0.151$	$p = 0.045$

* Significance at 5% level

Table 5 shows the Pearson correlation and students *t*-test between the Electric Pulp Tester and pulse oximetry value of tooth for the study group. The Pearson correlation was $r = 0.182$ with a p value of 0.045 which is statistically significant. The Pearson correlation was found to be negative and significant at 5% level.

Table 6: Oxygen Saturation Of Tooth And Finger - A Comparison.

	Pearson Correlation	***P* value ***
SaO_2 Tooth vs SaO_2 Finger	$r = 0.182$	$p = 0.016$

* Significance at 5% level

Table 6 shows the Pearson correlation and students t-test between the pulse oximetry values of tooth and finger for the study group. The Pearson correlation was $r = 0.182$ with a p value of 0.016 which is statistically significant. The Pearson correlation was found to be negative and significant at 5% level.

Table 7: Mean Values Of Comparisons Between Pulse Rate And Oxygen Saturation Readings Recorded In Finger And Tooth Of Each Subject.

S.No.	Group	Sample Size	PR Finger/O_2Finger PR Tooth/ O_2Tooth
			Mean ± S.D
1	**Study Group**	175	1.58 ± 0.47
2	**Control Group**	10	0

Table 7 shows the mean values of comparisons between finger and tooth pulse rates and oxygen saturation for each subject. The mean and standard deviation for PR/O_2Finger ÷ PR/O_2 Tooth of the study group is 1.58 ± 0.47 and for the control group is zero.

DISCUSSION

Pulse oximetry has emerged as the leading non-invasive monitoring device for determining the oxygen saturation and pulse rate of patients under intensive care and during sedation procedures even in the field of dentistry[4]. In the last two decades it had been used to measure the pulp vitality based on the oxygen saturation in pulp. Pulp vitality plays an important role in the diagnosis and treatment plan of traumatized tooth[19]. To understand the limitations of present pulp testing methods, a description of the qualities of an ideal pulp tester is indicated. An ideal pulp tester should provide a simple, objective, standardized, reproducible, non-painful, non-injurious, accurate and an inexpensive way of assessing the exact condition of the pulp tissues[8].

Unfortunately, the currently available methods (electrical, thermal and mechanical) fall short of nearly all of the above criteria[8]. Each of these test are subjective in nature that depends on the patient perceived response to stimulus, as well as the dentist interpretation of that response[12]. These methods are based on the stimulation of the nerve fibers which is not the ideal method to determine the pulp vitality status[12].

SeverSal authors have stated that blood circulation, not innervations, is the most accurate determinant in assessing pulp vitality[3,8,24]. The various methods which determine the pulpal blood circulation are Laser Doppler Flowmetry[17,46], Dual Wavelength Spectrophotometry[33] and Pulse oximetry[43,44]. The limitations of Laser Doppler Flowmetry in dentistry are lack of reproducibility, high cost and uncontrolled movement of the probe[39]. Dual Wavelength Spectrophotometry has been examined only in the laboratory settings which only detect the presence of hemoglobin in blood and not the circulation of blood. The drawback of pulse oximetry in pulp vitality testing is the failure of the available probe designs to accurately adapt to the human tooth.

Hence in our study a new dental probe was designed to adapt to the contour of the tooth and its ability was evaluated to determine pulp vitality.

Although both the primary and permanent dental models were given to the biomedical engineer, as a first phase, we started working with the permanent dental models. This probe was designed specifically for the maxillary central incisor tooth. The probe was stable over the tooth without the operator holding it and thus maintained a constant path length between the emitter and the sensor required for the pulse oximeter to make accurate calculations. The two halves of the probe clip are identical (mirror images) as they are made out of a single die and connected by a hinge pin and a low tension spring. The newly developed probe clip was easy to place, stable, inexpensive and could be sterilized (cold sterilization).

As described in the materials and methods, 185 children in the age group of 9 – 16 years were selected for the study to test the accuracy of new dental probe and hand held pulse oximeter in testing pulp vitality. Table I shows the distribution of the selected samples. Two hundred and seven subjects were examined of which 22 subjects were excluded from the study as they did not fulfill the selection criteria. Of the remaining 185 subjects, 175 were in study group and 10 in the control group.

According to Klien H(1978) [24] who evaluated the pulp response to an electric pulp tester during various stages of permanent anterior tooth development, found that a high percentage (89.2%) of the teeth, with completely open apices did not respond to electric pulp stimulation. Fulling HJ and Andreasen JO (1976)[15] compared and determined the threshold values of developing teeth for two commonly used electrometric pulp testers (Siemens Sirotest and Bofors Pulp Tester). The Siemens tester appeared to be equal to the Bofors tester with regard to reliability but showed an increased electrometric threshold value in developing teeth. Hence in our study we decided to exclude subjects with radiographic open apices of permanent anterior teeth.

The subjects included both boys and girls ranging from nine to sixteen years of age. Table 2 shows the age and sex distribution of the study subjects. The total numbers of boys were 110 and that of girls were 65. In age nine there was only one male and no girl. There were 29 subjects in age eleven of which 18 were boys and 11 were girls. In age twelve there were 28 boys and 13 girls. In age thirteen there were 29 boys and 26 girls. In age fourteen there were 20 boys and 13 girls. In age fifteen there were 13 boys and only 2 girls and in age sixteen there was only one male. The mean age for boys was 12.82 years and girls were 12.72 years.

The oxygen saturation from the finger and tooth of both the study group and control group were recorded. Table 3 shows mean and standard deviation values of the oxygen saturation of study and control groups for both finger and tooth. The mean oxygen saturation values of the study group from tooth were 83.66 ± 6.84 and that of the finger were 97.01 ± 2.96. The pulse oximeter recorded zero oxygen saturation from the tooth of the control group where as the oxygen saturation values from the finger of the control group was about 98.50 ± 0.52. There was a statistically significant difference between mean of oxygen saturation values of the tooth and finger of the study group ($p<0.05$).

The oxygen saturation values obtained in the teeth were lower than the oxygen saturation values recorded on the fingers of the subjects. The tooth oxygen saturation values were 13.35% lower than their associated finger readings. This was in consistent with the previous study by Munshi AK et al (2002)[31] on permanent incisors in which tooth and finger readings varied by 17.38%. But according to Schnettler JM and Wallace JA (1991)[44], who studied the permanent teeth found only 3% variation between tooth and finger readings, and Goho C (1999)[19] found the variation to be 3.41%, which could be attributed to the probe design. In most of the previous studies, the commercially available pulse oximeter ear probes were modified and used. Schmitt JM, Webber RL and Walker EC (1991)[43] attributed the lower oxygen saturation values of the tooth to diffraction of the infrared light by the enamel prisms and dentin. Fien et al (1977)[14] suggested that the lower oxygen saturation values for the pulpal circulation may be attributed to light ray scattering through the gingiva. As observed by Goho C (1999)[19], Schnettler

JM, Wallace JA (1991)[44] and Munshi AK et al (2002)[31], in our study also the oxygen saturation values of tooth recorded were lower than that of the finger.

The electric pulp tester responses of both the study and control group were also evaluated. Table 4 shows the Mean and Standard deviation values of the electric pulp tester values for the study and the control group. The study group value was about 2.29 ± 0.85 where as for the control group there was no response. According to Munshi AK et al (2002)[31], the mean electric pulp testing readings on permanent incisors was about 4.47 ± 0.76, which was in close comparison to our study. Millard HD (1973)[30] suggested that electric pulp tester is an important diagnostic aid for the evaluation of pulpal vitality. The interpretation of the response of the patient to electric pulp tester should be correlated with the findings from history, radiographs, clinical examination and from the reaction of a control tooth. Matthews B et al (1974)[26] studied whether the results given by an electric pulp tester can be used as a reliable indication of the vitality of a tooth by examining the pulps of the teeth histologically. He found no correlation between the thresholds of the vital teeth and the pathological state of their pulps. Fuss Z et al (1985)[16] evaluated the efficacy of various pulp testing agents to evoke a sensory response when applied to intact human teeth (electric pulp tester, ethyl chloride, dichlorodifluoromethane and carbon-dioxide snow). Results of the in-vivo test showed that electric pulp tester, dichlorodifluoromethane and carbon-dioxide snow produced the greatest percent of positive responses (94.8, 98.7 and 97.4 respectively) followed by ethyl chloride (53.2) and ice (32.5) which was statistically significant ($p < 0.01$).

Jacobson JJ (1984)[20] studied the probe placement site on the crown during electric pulp-testing procedure and found the lowest resistance on the occlusal two-thirds of the labial or buccal surfaces of maxillary incisors and premolars. More specifically, on the middle-third of the incisors and the occlusal-third of the premolars were shown to have the least resistance. The electrode placement area on the crown where the pulp nerve is first excited to threshold must be identified to avoid false-positive stimulation of surrounding periodontal nerves. This will decrease nerve damage and ensure the patient's cooperation and acceptance. Bender IB et al (1989)[2] studied the optimum placement-site of the electrode in electric pulp testing, where 2,387 recordings of 12 anterior teeth in 53 patients indicated that the incisal edge is the optimal placement-site for the electric pulp tester to determine the lowest response threshold. They also found that the application of the electric pulp tester to the incisal-edge region with exposed dentin produced the most significant decrease in the threshold response. In our study the probe was placed on the middle one-third, as the lowest threshold on incisors was obtained at this site as stated by Jacobson JJ (1984)[20] whereas the incisal edge decreased the threshold response and placing near the gingival one-third could stimulate the periodontal nerves and produce a false positive response, hence avoided.

Kolbinson DA, Teplitsky PE (1988)[25] studied the use of electric pulp testing with the operator wearing examination gloves and found statistically significant differences between electric pulp testing results for the same teeth with the operator's hands being gloved and ungloved. However, the mean differences in electric pulp testing results were small and were thought to be diagnostically insignificant for clinical situations. They also suggested that as long as the patient 'completes the circuit' by also holding the metallic handle of the electric pulp tester's probe, dentists can easily, reliably, and accurately use the electric pulp tester with examination gloves. As the results of this study proved that operator's hand being gloved or ungloved was diagnostically insignificant for clinical situations, in our study we chose to close the circuit with the operator hand (ungloved) itself as the patient was not allowed to take part in this procedure. Pantera EA et al (1992)[36] evaluated the effectiveness of the use of dental instruments (dental explorers and endodontic files) for bridging during electric pulp testing. Their findings indicated that electrically conductive dental instruments can be reliably used as bridging instruments with the electric pulp tester. Michaelson RE (1975)[28] evaluated with Sensitron electric pulp tester whether the amount of current needed to elicit a response varies with the conducting medium (Crest and Sensodyne toothpaste, EKG paste and water). Clinical results showed no appreciable difference between the medium used provided they were water and petroleum based. Hence, in our study we decided to use water based toothpaste (Colgate toothpaste) as the conducting medium.

The oxygen saturation values obtained from the tooth were correlated with the electrical pulp test readings. Table 5 shows the Pearson correlation and Students t-test between the electric pulp tester and pulse oximeter values of tooth for the study group. The Pearson correlation was about r = 0.151 with a p-value of 0.045, which was statistically significant. The Pearson correlation r = 0.151 was found to be negative i.e. as the values of the electrical pulp testing reading increased, the oxygen saturation values decreased. The correlation between electric pulp testing and pulse oximeter were found to be statistically significant using Students t-test at 5% level. This was in correlation with the previous study by Munshi AK et al (2002)[31] where r = 0.359 and p < 0.001.

The oxygen saturation values obtained from the tooth were correlated with the oxygen saturation values obtained from the fingers of the study group. Table 6 shows the Pearson correlation and Students t-test between the pulse oximetry values of tooth and finger for the study group. The Pearson correlation was about r = 0.182 with a p value of 0.016, which is statistically significant at 5% level. According to Goho C (1999)[19], Spearman correlation analysis of individual's finger and tooth oxygen saturation values showed a low correlation (0.15) for the permanent teeth subjects, which was consistent with our study. In our study the oxygen saturation values of the tooth were lower than the oxygen saturation of the finger, which was also in consistent with the findings of Munshi AK et al (2002)[31].

The values of pulse rate from both the finger and tooth were also recorded. After the readings were obtained, the following formula was applied to each set of finger and tooth values:

Pulse rate (finger) / oxygen saturation (finger)

Pulse rate (tooth) / oxygen saturation (tooth)

This provides for the individuality of readings and allows for some qualitative data. Table 7 shows the mean values of comparisons between finger and tooth pulse rates and oxygen saturation for each subject of the study and the control group. The mean and standard deviation for $\{PR/O_2(\text{finger})\} \div \{PR/O_2(\text{tooth})\}$ of the study group was 1.58 ± 0.47 and for the control group is zero. Values of all 175 subjects in the study group gave readings exhibiting significant similarities between finger and tooth, indicating that the tooth reading is indicative of pulsatile blood flow within the pulp. According to Schnettler and Wallace (1991)[44] the mean and standard deviation for $\{PR/O_2(\text{finger})\} \div \{PR/O_2(\text{tooth})\}$ of the study group was 1.08 ± 0.47 and zero for the control group, which was in consistent with our study. It is important to realize that this study was designed to determine whether or not the custom made pulse oximeter dental probe and the NONIN hand held pulse oximeter can detect blood flow in the human tooth. Attempting to analyze the differences between finger and tooth readings may be misleading due to different absorption aggregates of the enamel and dentine of the tooth as compared with the absorption of the bone in the finger.

Even though the newly developed probe clip was easy to place and stable, a better adaptable probe clip design could be achieved if the two halves of the clip are made from two dies separately designed to adapt the labial and the lingual contours. As this probe was specially designed for the maxillary central incisor tooth, other tooth cannot be tested. Therefore a universal probe design without any exposed spring component that could adapt to any tooth irrespective of its contour would be a more appropriate pulse oximeter dental probe and our research is continuing to achieve such a pulse oximeter dental probe design.

SUMMARY AND CONCLUSION

The aim of the study was to design and develop a probe that adapts to the contour of the permanent central incisor and to evaluate its efficiency in detecting the vascular integrity of human teeth and to compare it with the electric pulp tester. The newly designed probe was able to adapt to the contour of the central incisor and was stable in its position without the operator holding it. It was used to evaluate pulp vascularity on 185 subjects of which 175 subjects were in the study group and 10 in the control group. The result obtained was also compared with the results of the electric pulp tester. The conclusions derived from the results of this study are:

1. The newly developed probe and the NONIN hand held pulse oximeter were able to detect the blood flow in the tooth of the study group and recorded values which were lower than the finger readings.
2. Oxygen saturation values of the tooth compared to the Oxygen saturation values of the finger was statistically significant with a p value of 0.016.
3. Oxygen saturation values of the tooth compared to the electric pulp tester values was statistically significant was with a p value of 0.045.

Consistent pulse oximetry readings detected by the newly developed probe in this study have confirmed the pulsatile blood flow and its oxygen saturation in tooth. Moreover this study shows that pulse oximetry is an effective, objective and a non-invasive method for the clinician to determine pulp vitality of the permanent incisors. It can also be used in primary and immature permanent teeth where patient co-operation and incomplete pulp innervations reduces the effectiveness and reliability of thermal and electric pulp testers. Further study in the probe design which could be used universally for all teeth is in progress and its success will be a boon for the diagnosis of pulp vitality.

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