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Review Article

Pulse Oximetry - Working Principles in Pulpal Vitality Testing

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ABSTRACT

Assessment of pulp vitality is a crucial diagnostic procedure in the practice of dentistry and for treating traumatized teeth. 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, anaesthetic testing or direct dentine stimulation (test cavity). These modalities falsehood of the ideal pulp tests on several criteria. 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 anaesthesia. This article gives an insight into the working principles on pulse oximetry as a puplal vitality aid. Method is based on the Beer-Lambert law, which relates the concentration of a solute to the intensity of light transmitted through a solution.

Keywords: Pulp oximeter, Pulp vitality, Thermal Stimuli, Pulpitis

INTRODUCTION

Assessment of the teeth vitality is complicated by the fact that the dental pulp is enclosed within calcified tissues, and does so indirectly. [1] The assessment of pulp vitality is a crucial diagnostic procedure in the practice of dentistry [2] and for treating traumatized teeth. [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,

anaesthetic testing or direct dentine stimulation (test cavity). 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, or when electric current applied to the tooth surface is conducted to the periodontal ligament, thus stimulating periodontal nerve fibres. [4] 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 tests are subjective tests that depend upon patient's perceived response to a stimulus, as well as the dentist 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 non vital if only its neural component is injured. These situations are commonly encountered with recently traumatized teeth [7] causing momentary anaesthetic effect. On the other hand, the pulp nerve fibres 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 4-5 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 anaesthesia. This article gives an insight into the working principles on pulse oximetry as a puplal vitality aid.

History:

Two early researchers who stand out are Carl Matthes and Glen Millikan. In 1935, Matthes built the first device that continuously measured human blood oxygen saturation in vivo by transilluminating tissue. He used two wavelengths of light: one that was sensitive to changes in oxygenation and another that was not. The second wavelength, in the infrared range, was used to compensate for changes in tissue thickness, hemoglobin content, and light intensity. This device could follow trends in saturation but was difficult to calibrate. J.R. Squires, in Great Britain developed a similar device that was calibrated by compressing the tissue to eliminate the blood. This same calibration technique was later adopted in the first oximeters use in the operating room.

In the early 1940s, Glen Millikan coined the term "Oximeter" to describe a light weight device he developed for aviation research. Later in the 1940s,

oximeters similar to Millikan's were used by Earl Wood and others in the operating room, where they were noted to detect significant desaturations even during routine anesthetics.

In its initial clinical development, the ear oximeters had several limitations. It was a delicate instrument that required a technician to operate and maintain. The earpiece was large, difficult to position, and produced enough heat to cause second degree burns on the pinna. Furthermore it required calibration on each patient prior to use. During the 1950s, Earl Wood devised a modification of the Millikan ear piece that was used in many clinical and laboratory investigations. Although the ear oximeter showed promise in some settings, it was still considered a research tool.

In the 1970s, Hewlett-Packard marketed the first self calibrating ear oximeter. This device used eight wave lengths of light to determine hemoglobin saturation. This method over-specified the system, because only four wavelengths are theoretically required to solve for hemoglobin saturations, as we shall see below. Hewlett-Packard oximeter also used the method of heating the ear to "arterialize" the capillary blood. This oximeter quickly became a standard clinical and laboratory tool in pulmonary medicine. Although it was demonstrated to be accurate for intraoperative monitoring, its size and expense, and the cumbersome nature of the ear probe prevented its acceptance as a routine monitor. At this time, all oximeters produced various light source wavelengths by filtering white light. The filtered light was then transmitted to and from the tissue through fiber optic cables.

The clinical utility of the noninvasive oximeter in the operating room was rediscovered in the 1980s by William New, an anesthesiologist at Stanford University. Realizing that a continuous noninvasive monitor of oxygenation would be useful to anesthesiologists, New developed and marketed a pulse oximeter to this group.

Pulse oximetry:

Oximetry refers to the determination of the percentage of oxygen saturation of the circulating arterial blood. [9] Pulse oximetry has been recommended as a standard of care for every general anesthetic. This technique, virtually unknown in anesthesia 25 year ago, has been so readily adopted now for several reasons. The device provides valuable data regarding blood oxygenation and this information is obtained easily, continuously, and noninvasively. The pulse oximeter is based upon two physical principles. First, the light absorbance of oxygenated hemoglobin is different from that of reduced hemoglobin at the oximeter's two wavelengths. Second, the absorbances at both wavelengths have a pulsatile (AC) component, which is the result of the fluctuating volume of arterial blood between the source and detector. Given these two facts and no other physics or physiology, the engineering design of the pulse oximeter is clever but straightforward.

Pulse oximetry is a relatively recent advancement in noninvasive monitoring of oxygen saturation of blood and pulse rate of patients under intensive care or during sedation procedures. No other electronic monitoring device has found widespread use in the operating room more quickly than has the pulse oximeter. [9] It requires no special training or new skills on the part of the user. It can warn of a number of disasters in progress including airway disconnection, loss of oxygen supply, severe increase in venous admixture, or loss of a pulse.

The Physics and Physiology of Pulse Oximetry:

BEER'S LAW

In the 1930s Matthes used spectrophotometry to determine hemoglobin oxygen saturation. This method is based on the Beer-Lambert law, which relates the concentration of a solute to the intensity of light transmitted through a solution.

$I_{trans} = I_{in}e^{-A}$

$A = DC\square$

Where I_{trans} =intensity of transmitted light; I_{in} =intensity of incident light; A = absorption; D= distance light is transmitted through the liquid (path length); C= concentration of solute (hemoglobin); $\square$ = extinction coefficient of the solute (a constant for a given solute at a specified wavelength). Thus, if a known solute is in a clear solution in a cuvette of known dimensions, the solute concentration can be calculated from measurements of the incident and transmitted light intensity at a known wavelength. The extinction coefficient $\square$ is a property of light absorption for a specific substance at a specified wavelength. In a one-component system, the absorption A is the product of the path length, the concentration, and the extinction coefficient, equation la. If multiple solutes are present, A is the sum of similar expression for each solute. The extinction coefficient for various hemoglobin species in the red and infrared wavelength range are shown in figure 1.

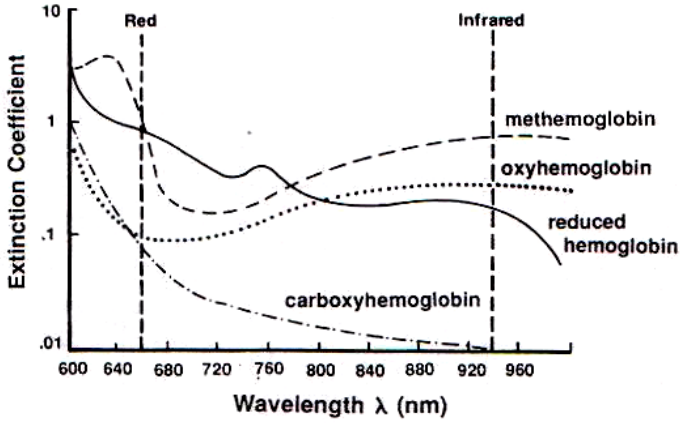

Figure 1: Laboratory oximeters \ principle to determine hemoglobin concentration.

Laboratory oximeters use this principle to determine hemoglobin concentration by measuring the intensity of light transmitted through a cuvette filled with a hemoglobin solution produced from lysed red blood cells. For Beer's law to be valid, both the solvent and the cuvette must be transparent at the wavelength used, the light path length must be know exactly, and no absorbing species can be present in the solution other than the known solute. It is difficult to fulfill these requirements in clinical devices; therefore, each instrument theoretically based on Beer's law also requires empirical correction to improve accuracy.

When oximetry is used to measure hemoglobin saturation, Beer's law must be applied to a solution containing four unknown species: O_2 Hb, Hb, COHb, and MetHb Expanding the above equation to a four-component system results in an absorption given by:

$A=D_1 C_1 \square + D_2C_2\square_2 + D_3C_3\square_3 + D_4C_4\square_4$

The subscripts 1 through 4 correspond to the four hemoglobin species. If the path lengths are the same, then D can be factored out:

$A = D (C_1 \square_1 + C_2\square_2 + D_3\square_3 + D_4\square_4)$

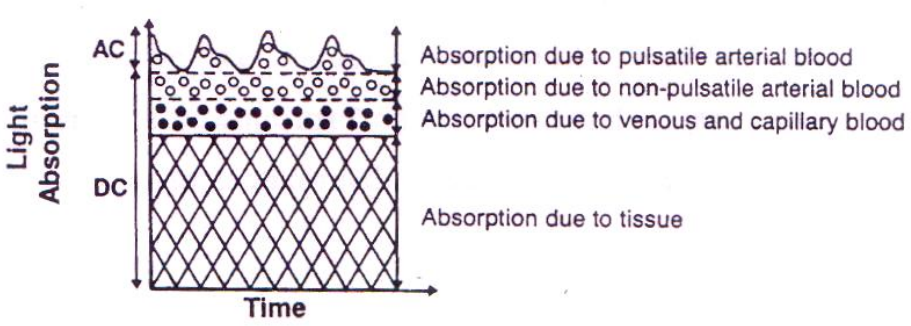

Figure 2: Schematically illustrates the series of absorbers in a living tissue sample

Pulse oximeters deal with the effects tissue and venous blood absorbances in a completely different way. At component, which is attributed to the pulsating arterial blood. The baseline or DC component represents the absorbances of the tissue bed, including venous blood, capillary blood, and nonpulsatile arterial blood. The pulsatile expansion of the arteriolar bed produces an increase in path length, thereby increasing the absorbance. All pulse oximeters assume that the only pulsatile absorbance between the light source and the photo detector is that of arterial blood. They use two wavelengths of light: 660 nanometers (red) and 940 nanometers (near infrared). The pulse oximeter first determines the AC component of absorbance at each wavelength and divides this by the corresponding DC component to obtain a "pulse-added" absorbance that is independent of the incident light intensity. It then calculates the ratio (R) of these pulse-added absorbances, which is empirically related to SaO_2. [10]

CONCLUSION

The technology with which pulse oximeter works can be adapted for the true objective evaluation of the pulpal vitality testing, which could be a great technique in endodontics.

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