

Pulse Oximetry: A New Tool in Pulpal Vitality Testing

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Abstract:

Over the years, the thermal and electrical tests have been considered to be a suitable means of assessing the vascularity and vitality of the tooth pulp. Pulse oximetry is an effective, objective, oxygen saturation monitoring technique broadly used in medicine for recording blood oxygen saturation levels. It can also be used in endodontics for differential diagnosis of vital pulps and necrotic ones. However, there are some limitations inherent in the technology of pulse oximetry, such as the effect of increased acidity and metabolic rate, which causes deoxygenating of hemoglobin and changes in blood oxygen saturation, also movements of the body or probe can complicate readings. This test produces no noxious stimuli, therefore, apprehensive or distressed patients may accept it more readily than routine methods. A review of the literature and a discussion of the potential application of this system in endodontics is presented.

Key Words: Pulp vascularity, pulse oximetry, endodontics

Introduction:

Diagnosis is the art of identifying the problem and using scientific knowledge to determine the cause of the problem. The purpose of diagnosis in endodontics is to assess the condition of a tooth and to identify the cause of the discomfort. To determine the vitality of a pulp, the ideal tests used should be objective, painless, and reliable. Currently the most common tests for this purpose are sensibility tests (Kenneth et al, 2011). A major limitation of these tests is that they subjectively imply vitality through sensory responses.

An alternative method would be to evaluate the vascularity of the pulp. This would be a more precise test, given the essential role of the pulp circulation in maintaining the tissue health. The evaluation of circulatory status of the pulp has been proposed to assess pulp vitality. Oximetry, the measurement of oxygen bound to hemoglobin is an advance in anesthesiology. Pulse Oximetry is a well established, noninvasive, direct, completely objective method for measuring vascular health by evaluating oxygen saturation levels (Noblett et al, 1996).

Histroy:

The concept of pulse oximetry is not new. In 1935 Carl Matthes built the first device to continuously measure blood oxygen saturation *in vivo* by transilluminating tissue. He used two wavelengths of light, one of which was sensitive to changes in oxygen

saturation and the other, which was in the infrared range, was used to compensate for changes in tissue thickness, hemoglobin content and light intensity. Although useful in following trends in saturation, the device had limitations as it was difficult to calibrate and absolute values could not be obtained.

Squire in 1940 devised a technique of calibration by compressing tissue to eliminate the blood. This was later incorporated in the first generation of pulse oximeters used in the operating theatres. In the early 1940s, Millikan coined the term "oximeter" to describe a lightweight earpiece to detect the oxygen saturation of hemoglobin, for use in aviation research to investigate high altitude hypoxic problems. Thus, the clinical utility of pulse oximeters was evident to researchers in the field more than half a century ago.

In 1964, a surgeon, Robert Shaw, built a self-calibrating ear oximeter, which was marketed by Hewlett Packard in 1970 for use in physiology and cardiac catheterization laboratories (Stephen et al, 1951).

The year 1972 marked the greatest step forward in monitoring oxygenation, ironically as an incidental finding. Until then, in order to isolate arterial blood for transillumination, oximeters relied on compression and heating the earlobe to remove signals from venous and capillary blood which often caused burns. Takuo Aayogi in 1974 at the Nihon Kohden Corporation working on a dye dilution cardiac output monitor using a ear densitometer, found artifacts due to pulsatile flow. He noted that the washout curves he was measuring, were modified by pulsatile variations. While attempting to eliminate these variations, he discovered that the absorbency ratios of these

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pulsations at different wavelengths varied with the oxygen saturation. Thus, he could minimize the pulsatile component by balancing the red light signal with an infrared light signal where the dye had no absorption. As this compensation was dependant on oxygen saturation, he incorporated the technique of reducing noise in his signal to measure oxygen saturation. The subsequent development of light emitting diodes (LEDs), photo detectors and microprocessors further refined the technique, and pulse oximeters were widely introduced into clinical practice.

Modern pulse oximetry was born with the realization that pulsatile changes in light transmission through living tissues are due to alteration of the arterial blood volume in the tissue. Measurement of the pulsatile component would eliminate the variable absorption of light by bone, tissue, skin, pigment, etc from analysis. The most important premise of pulse oximetry, therefore, is that the only pulsatile absorbance between the light source and the photo detector is that of arterial blood.

Two wavelengths of light are used; 660 nanometers (red) and 940 nanometres (near infrared). At 660nm, reduced hemoglobin absorbs about ten times as much light as oxyhemoglobin. At the infrared wavelength, (940nm), the absorption coefficient of oxyhemoglobin is greater than that of reduced hemoglobin. The pulse oximeter directly senses the absorption of red and infra red light, and the ratio of pulsatile to nonpulsatile light at the red and infrared wavelengths are translated through complex signal processing to a function of the arterial oxygen saturation. A microprocessor integrates the data, and through an elaborate calibration algorithm based on human volunteer data, the oxygen saturation can be estimated (Comroe & Botelho, 1947).

Principles of Oximetry:

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 (Severinghaus & Astrup, 1987).

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

$$A = DC\epsilon$$

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); ϵ = extinction

coefficient of the solute (a constant for a given solute at a specified wavelength). Thus, if a known solute is in 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 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 1a. If multiple solutes are present, A is the sum of similar expression for each solute. 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 Beers lambert law also requires empirical correction to improve accuracy (Jayashankar et al, 2012; Radhakrishna et al, 2002).

Equipment:

1. Pulse oximeter probe/ pulse oximeter sensor (POS):

It contains two light-emitting diodes (LEDs) - One transmits red light (approximately 660 nm) and the other transmits infrared light(900-940nm). It operates at 500 on/off cycles /sec.

2. Pulse oximeter monitor:

It gives digital display of oxygen saturation values,connects to POS.

3. Photo detector:

It detects the amount of light absorbed by oxygenated and deoxygenated hemoglobin and connected to a microprocessor.

There are no Oximetry probes specific for the teeth in the market.

Gopikrishna et al (2006) developed a custom made POS holder for an existing Nellcor multi-site sensor and showed the utility of the pulse oximetry dental probe in the assessment of human pulp vitality.

Mechanism of action:

The pulse oximetry sensor consists of two light emitting diodes, one to transmit red light (640nm) and the other to transmit infrared light (940nm), and a photo

etector on the opposite side of the vascular bed. The light emitting diode transmits light through a vascular bed such as finger, toes or ear. Oxygenated hemoglobin and deoxygenated hemoglobin absorb different amount of red /infrared light. The pulsatile change in the blood volume causes periodic changes in the amount of red/infrared light absorbed by the vascular bed before reaching the photo detector. The relationship between the pulsatile change in the absorption of red light and the pulsatile change in the absorption of infrared light is analyzed by the pulse oximetry to determine the saturation of arterial blood. The information collected is converted into digital signals that are processed by the oximetry computer. A numerical estimation of the hemoglobin oxygen saturation is then produced and displayed. The machines can produce audible and visible signals to alert the doctor to change in the pulse rate and oxygen saturation. The machines safety mechanism includes low oxygen saturation and pulse rate range alarms. Displacement of finger probe also causes an audible signal. The alarms can be set independently to desired range (Abd- Elmeguid & Yu, 2009).

The response to current clinical tests indicate only that the sensory fibers are vital and 10%-16% of the results of these test are false. The nervous system, which is highly resistant to inflammation, may remain reactive, even though all surrounding tissues have degenerated; therefore testing the sensory supply may give a positive response when the pulp is damaged i.e., false positive result (Petersson et al, 1999).

This test may also leave the patient with an unpleasant sensation. A false-negative result (i.e. no response) may be obtained in cases of calcific metamorphosis, recently traumatized teeth, and incomplete root formation (Mickel et al, 2006). The vitality of the pulp is determined according to the health of the vascular supply and not of the sensory fibers. The pulp receives its blood supply through thin-walled arterioles entering through the apical and accessory foramina. These arterioles run longitudinally through the centre of the pulp, branching out to its periphery where they form a capillary network in the sub-odontoblastic area. These capillaries do not enter the dentin; they drain into the venules that run alongside the arterioles and pass out through the same apical foramen. Different methods may be used to assess the blood flow in the pulp (Abd-Elmeguid & Yu, 2009). Advantages of Pulse Oximetry are that it is effective, objective, measures pulp vascularity, applicable to

recently traumatized permanent teeth, non invasive, can be used in uncooperative, apprehensive patients, no unpleasant sensation, reproducible readings and data storage for further references (Radhakrishnan et al, 2002). There are some limitations inherent in the technology of pulse oximetry. They may be classified as intrinsic and extrinsic (Jafarzadeh & Rosenberg, 2009).

1. Intrinsic Factors: Increased acidity, increased carbon dioxide in the blood stream, increased metabolic rate arising from inflammation, intra venous dyes causing false low oxygen saturation level and presence of other gases such as carbon dioxide. For excellent accuracy, oxygen saturation level should be in the range of 70% to 100%.

a. Patient variables: Low peripheral perfusion, increased venous pulsation, hemoglobin disorders, pigmented patients vasoconstriction, hypotension, and body movement will cause false /delayed readings, extensively restored teeth, nail polish, if blue, green, or black causes inaccurate saturation readings

b. Environmental factors: Electro-cautery near the sensor, ambient light interferences, and ipsilateral blood pressure reading.

2. Extrinsic factors: Probe movement and overhead xenon arc lamps. The critical requirement for using pulse oximetry in dentistry is that the sensors should conform to the size, shape and anatomy of the tooth and that the LED and photo detector be parallel to each other and the probe should be held firmly. An innovative technological approach to reject motion artifact is termed as Masimo signal extraction technology (Kahan et al, 1996).

Laser Doppler Flowmetry (LDF) is another new innovation. It is an accurate, non invasive, reproducible, reliable method of assessing blood flow in microvascular systems with a diode that projects an infra red light beam through the crown and pulp chamber. Unfortunately Laser Doppler Flowmetry takes about an hour to produce recordings, making it impractical for dental practices (Polat et al, 2005).

On comparing Pulse oximetry vs conventional pulp sensitivity tests, Gopikrishnana et al (2006) found Pulse Oximetry to be more accurate. Sensitivity of the pulse oximetry was 100%, cold test 81%, electric pulp test 71% in a study reported by Abd-Elmeguid & Yu (2009).

Conclusion:

Information about the physiology of pulpal pain and the sensory fibers causing this pain, together with information gathered from the patient, and the use of appropriate devices to test pulp sensitivity and vitality are very critical to reaching an accurate diagnosis on which to base an appropriate treatment plan. Multiple devices that test pulp viability are available on the market, but they test the viability of nerve fibers as measures of pulp vitality resulting sometimes in false positive or false-negative results. These can lead to unnecessary endodontic procedures if these tests are not substantiated with results of other diagnostic measures. Pulpal blood flow, which is at least as important as testing the neural supply of the pulp, must also be examined. Although still being studied, methods to test blood flow look very promising and should soon be in use in the dental clinic.

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