

Comparing Pulse Oximetry and Laser Doppler Flowmetry as a Diagnostic Tool for Pulpal Vitality

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Abstract

The impact of oral health on the health of all people in the world and the improvement of living standards in recent years has led to increased attention to the factors affecting oral health. One of the important factors in oral health is early monitoring of dental and gingival microcirculation to be used in the diagnosis of many oral diseases in the early stages. Due to the location of the teeth in the oral cavity covered by the gums, direct monitoring of dental and gingival health is a complex task that requires specialized tools to enable routine clinical use in dentistry in a simple, painless, cost-effective and non-invasive. Pulp vitality normally represents the vascular supply of tooth innervated by sensory fibers. Most of pulp sensitivity tests such cold, thermal and electric tests are dependent on the stimulation of nerve fibers with false positive and false negative response in traumatized and necrotic teeth or patients under the influence of drugs or alcohol can lead to unnecessary endodontic procedures. Current therapeutic decisions in dentistry are made using clinical examination, pulp sensitivity tests, and radiography which are practical but not enough to provide a valuable diagnosis information of vascular supply in dental pulp, especially in procedure like root canal. The important of finding a tool to assist in the pulp diagnosis leading to an appropriate treatment planning, this paper is providing a comprehensive review of current pulp testing methods by pulse oximetry and laser Doppler flowmetry.

Keywords: pulse oximeter; laser Doppler flowmetry; gingival; microcirculation; non-invasive

Introduction

Diagnosis in dentistry is the result of the process of combining and analyzing various data such as questions, observations, examinations, and various tests to determine abnormalities. A well-controlled treatment plan, as a result, can only be achieved through careful steps [1, 2, 3]. The human tooth is made up of several parts, but the pulp can be called the heart of the tooth, which is made up of blood vessels and nerves, which are responsible for keeping the tooth alive by receiving nutrients through a complex network of micro-vessels. The most routine tests for assessing pulp viability in dentistry are sensitivity tests that are subjective [1]. Accurate assessment of pulp status is one of the biggest diagnostic challenges in clinical practice and more complex in pediatric dentistry, where dentist attempts to measure the neurological response without necessary cooperation [1, 2]. The new pulp testing devices that are under development, detect the blood supply of dental pulp would be considered as more accurate, reliable and non-invasive devices for routine practice in dentistry. Two devices that have the potential to provide simple, objective, repeatable, painless, accurate, and inexpensive tests to assess the condition of pulp tissue “laser Doppler flowmetry” and “pulse oximetry” are compared.

Laser Doppler flowmetry

Laser Doppler flowmetry (LDF) is a noninvasive, painless, electro optical technique, which measures pulp blood flow. This technique, was described since 1980s, uses the Doppler shifted light as a carrier of information. Light will be absorbed or scattered in contact with human tissues, depending on its characteristics. The properties of human tissues are important for a variety of laser applications in order to understand the mechanisms of interaction between light and tissue [4-8].

History

Since the first time Doppler laser method was used by Yeh and Gummins to measure velocity of red blood cells in capillaries in 1964, this method has been developed by different people to measure blood speed, which has been proved as a noninvasive, painless, objective and reliable method to measure pulpal blood flow. Laser Doppler flow was developed to assess blood flow in micro vascular systems in the retina, renal cortex and skin [7, 9].

This technology used a helium-neon (He-Ne) laser at wavelength 632.8 nm, that when scattered by red cells in blood, a frequency shift happened according to the Doppler principle. A fraction of back-scattered light from the illuminated area was detected and processed to produce a signal represents a function of the red cell flux. This information was used as a measure of blood flow in percentage of full-scale deflection and adopted to blood flow monitor for animal and human teeth. In order to achieve the best type of laser and wavelength, different ranges of wavelengths of semiconductor lasers have also been used: 780 nm and 780-820 nm, there are reports of using a wavelength of 810 nm which indicates good sensitivity but specificity is weak. The wavelength of 633 nm is also a wavelength that showed good properties but poor sensitivity. There are reports of the use of non-laser light in the range of 576 nm to detect pulp perfusion. In general, it can be said that light with higher wavelengths such as infrared in the range of 780-810 nm has a greater ability to penetrate the enamel and dentin than red light with shorter wavelengths of 632.8 nm. The lasers used for LDF are usually low-power lasers with a power of 1 or 2 mW, and no damage has been reported in this method [7, 9, 10].

The first fiber optic laser Doppler flowmetry was introduced in the early of 1980 [8].

In 1986, Gazilius et al. for first time described the use of laser Doppler flowmetry (LDF) in human teeth. By detecting heart rate oscillation in the laser Doppler flowmetry, they were able to show their correlation with simultaneous electrocardiograms (ECG). LDF produced a signal corresponding to ECG waveform for teeth with vital pulp, teeth with necrotic pulp did not show synchronous signals, but produced very rapid irregular oscillations attributed to motion artifacts. Although the value of the method was well documented, its high cost and difficulty in clinical use prevented its widespread introduction [1, 4, 9].

Technology

The Doppler Effect is the basis of LDF that was first described in 1842 by Austrian physicist Christian Doppler. It explains the frequency shift that a wave undergoes when emitted from an object that is moving away from or towards an observer. Laser Doppler flowmetry is an optical method that enables measuring the number and velocity of particles conveyed by a fluid flow to be measured. The particles size must be enough big to scatter sufficient light for signal detection but small enough to follow the flow faithfully between 1-20 μ m. The original technology of laser Doppler flowmetry used helium-neon (He-Ne) laser with wavelength at 632.8nm (red), different sources of other semi-conductor lasers have also been used from 780 (near-infrared) nm and 780-820nm. Laser light with two equal intensity beams through a fiber optic probe transmitted to the dental pulp in front of tooth surface. The scattered light beams from moving red blood cells in the blood will be frequency-shifted or Doppler-shifted whilst those from the static tissue remain without any shift in frequency. The reflected light, composed of Doppler-shifted and upshifted light, is returned by a different fiber optic within the same probe to photodetectors in the flow meter to be processed and produce a signal (Fig. 1).

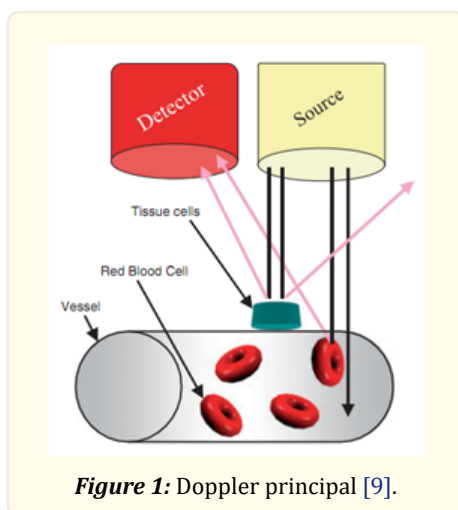


Figure 1: Doppler principal [9].

The photodetectors convert the reflected light that is composed of Doppler shifted and upshifted into a semi-quantitative measurement of blood flow called FLUX, the Flux signal by an algorithm in the LDF device, calculated. The Flux can be simplified as a function that represents concentration of red blood cells and their mean velocity, because Flux is the number of moving red blood cells per second times that is actually mean velocity. The method of using the Flux signal to assess vitality of tooth is to compare the size of the Flux signal obtained from a healthy vital control tooth with a suspected non vital tooth. The pulse signal of a tooth with a vital pulp should be greater than that of a tooth with a non-vital pulp, in teeth without pulp blood flow, usually only irregular fluctuations can be observed in contrast to the concurrent ECG reading. The optical properties of the tooth change with the necrosis of the pulp, which can cause changes in the LDF signal that are not necessarily due to differences in blood flow. Since the red blood cells in the tooth represent the vast majority of the moving objects inside the tooth, the measurement of backscattered Doppler shifted light can be considered as an indicator of PBF. The LDF assesses dynamic changes in blood flow by detecting the movement of blood cells in a small volume of tissue. Most current laser Doppler flowmetry devices have the ability to display Flux and perfusion units (PUs), these PUs are optional and can be calculated by the software of each device. None of the current Doppler laser devices can show absolute amount of blood flow perfusion (e.g. mL min⁻¹ 100 g⁻¹ tissue), so PUs are never comparable between different types of devices, and even for one device may be different in different situation, unless the device is frequently calibrated using special suspensions of particles in liquid that have known inherent vibration. The laser beam of laser Doppler flowmetry is a low power beam ranging from 1-2 mW. The penetration of LDF beam in tooth is approximately 4-6 mm in extracted teeth, the contact and non-contact of probe to tooth surface has not significant influence on penetration of beam to depth of tooth [6, 9, 11-13].

Indications

Laser Doppler flowmetry has been used in pulpal blood flow measurements for:

1. The pulpal status in modern treatment planning is important to differential diagnosis of dental pain, especially in necrotic pulp. LDF has good potential to be used for assessment of pulpal vitality [12].
2. Sensitivity tests in children are not reliable, because they are subjective and based on the patient's answer; in children, an accurate answer cannot be expected. The LDF seems to be a better choice in measurement of pulpal blood flow in deciduous incisors [7].
3. Some of periapical radiolucency may have nonendodontic origins, so LDF can help in differential diagnosis of these radiographic views [9].
4. Using LDF has been shown that the hemodynamics of human pulp is age dependent and reduced with age. LDF can be used for

monitoring of changes in PDF [9, 14].

5. Exercise has an effect on PBF of about 38% of the resting level, LDF can be used for this monitoring.
6. LDF can be used to monitor the reaction of local and systemic pharmacological agents (including local anesthetics).
7. One of indication of LDF can be monitoring of reactions to electrical or thermal pulp stimulation.
8. Due to the effect of intrusive force in reducing PBF, another application of LDF can be to monitor pulp reactions to orthodontic procedures.
9. Some of surgeries like segmental maxillary osteotomy or Le fort I osteotomy reduce pulpal sensibility, LDF can be used in post-operative monitoring after such orthognathic surgery.
10. Trauma may damage nerves of teeth and make their response negative respond to the pulp test, although they have blood circulation and maintain their vital function, in these cases LDF can be used as an accurate and objective technique to assess pulp vitality.
11. Vascular monitoring of replanted teeth can be one of indication of LDF to predict the condition of the pulp in vital teeth compared to non-vital teeth.

Advantage

Studies showing advantages of LDF as follow [9, 10, 14]:

1. LDF noninvasive nature helps to promote patient cooperation and acceptance.
2. Accurate.
3. Reliable.
4. Reproducible.
5. Painless.
6. Luxation injuries.
7. Independence of patient cooperation makes it useful for use in children.

Limitation

Although the use of LDF is effective and reliable for some body tissues, the limited transparency and multiple reflections of the teeth have cast doubt on its validity for assessing pulp status. Some studies find this technique very reliable, but only under certain controlled conditions [1, 2, 4, 6, 15].

1. Laser Doppler flowmetry is expensive for use in a dental office.
2. The probe should be held motionless and in constant contact with the tooth, to be accurate for reading.
3. The laser beam must interact with the moving cells within the pulpal vasculature, so is sensitive to direction of beam.
4. LDF evaluation of traumatized teeth should be performed 4 weeks after the initial trauma and repeated at regular intervals of up to 3 months.
5. Blood pigments within a discolored tooth crown can interfere with transmitted laser light, so should be careful about false positive results from stimulation of supporting tissues.

Pulse Oximetry

Since the early 1980s, when pulse oximetry was introduced, this non-invasive method of monitoring arterial oxygen saturation in the patient's blood (SpO_2) has become a standard method in the clinical environment due to its simple application and high value. Prior to pulse oximetry, the required information was obtained from the usual method of drawing blood from patients and analyzing samples at regular intervals - several times a day or even several times an hour - using the laboratory equipment of a large hospital. These instruments were laboratory analyzers or blood gas analyzers or homoximeters. Blood gas analyzers use chemical sensors to determine the partial pressure of blood oxygen (pO_2). Homoximeters work according to the principles of spectroscopy and directly

measure the ratio of oxygenated hemoglobin to total hemoglobin in the blood sample (SaO_2) [16-18].

Pulp vitality assessment is an important diagnostic procedure for monitoring dental health status in dentistry. Pulp vitality test is crucial in monitoring the state of health of dental pulp, especially after traumatic injuries, traditional pulp testing methods such as thermal and electrical depend on the innervation and often yield false positive and negative responses [19, 20]. In addition, each is a subjective test that depends on the patient's perceived response to a stimulus as well as the dentist's interpretation of that response. The Pulse oximetry is a noninvasive oxygen saturation monitoring device widely used in medical practice for recording blood oxygen saturation. This technique has been used to detect vascular integrity in the tooth. Its wide acceptance in the medical field results from its ease of application and its capability of providing vital information about the patient's status [19, 21].

History

The concept of pulse oximetry is not new, after discovering that hemoglobin carries oxygen in the blood by Geory Gabriel Stokes in 1864, the first oxygen saturation meter developed by Carl Matthes in 1935 with 2 wavelength light source, red and green, which changed later to red and infrared [9].

In 1940 J.R. Squire developed a technique for calibrating tissue compression to remove blood. It was later incorporated into the first generation of pulse oximeters used in operating rooms [7].

In the early 1940s, Glen Millikan a British scientist introduced the term "oximeter" in detect the oxygen saturation of hemoglobin, for use in aviation research to investigate high altitude hypoxic problems during second world war, which soon, similar devices were used during anesthesia [22].

Hewlett Packard lunched the first ear oximeter by using eight wavelengths of light, it was expensive and large used primary in sleep laboratories and in pulmonary functions. An ear probe was connected to the main oximeter via a fiber-optic cable, which contained a tungsten-iodine lamp and interference filters to select the wavelength as the light source and receiver. It has long been a "gold standard" for oximetry and has even been used to validate the first pulse oximeter in clinical trials. The real breakthrough came in the 1980s with a new generation of tools and sensors that were smaller, easier to use, and less expensive. These new instruments used a slightly different principle from the old, purely experimental multi-wavelength technology. Instead of using constant absorption values in eight different spectral lines measured through the earlobe, the new pulse oximeters used the pulsating component of arterial blood in only two spectral lines. The required light was easily generated by two light emitting diodes (LEDs) with controlled wavelengths. Small LEDs and light emitting diodes allow the installation of optical components directly on the sensor applied to the patient, avoiding the need for clumsy fiber optic packages [1, 23].

In 1972 Takuo Aayogia Japanese bioengineer at Nihon Kohden, by discovering that the absorbency ratios of pulsations at different wavelengths varied with the oxygen saturation, developed a pulse oximeter based on the ratio of red to infrared light absorption in blood. Since then, oximetry became clinically usable [2].

Advances in the production of pulse oximetry components such as light emitting diodes (LEDs), photodiodes, and microprocessors further enhanced this technique. The new generation of pulse oximetry eliminates the variable absorption of light by bone, tissue, skin, pigment, etc. from the analysis by using a pulsating component, and turns the pulse oximeter into a device with widespread use in various clinical practices.

The Biox Technology introduced the first commercial pulse oximeter in 1981, initially it was focused on respiratory care and later expanded into operating rooms. Since then, other manufacturers have entered the market and the pulse oximeter technology has improved significantly.

In 1987 Pulse Oximetry becomes part of a standard procedure in administering general anesthetic in US. The use of oximetry quickly spread to other hospital units, such as emergency rooms, recovery rooms, neonatal units, and intensive care units.

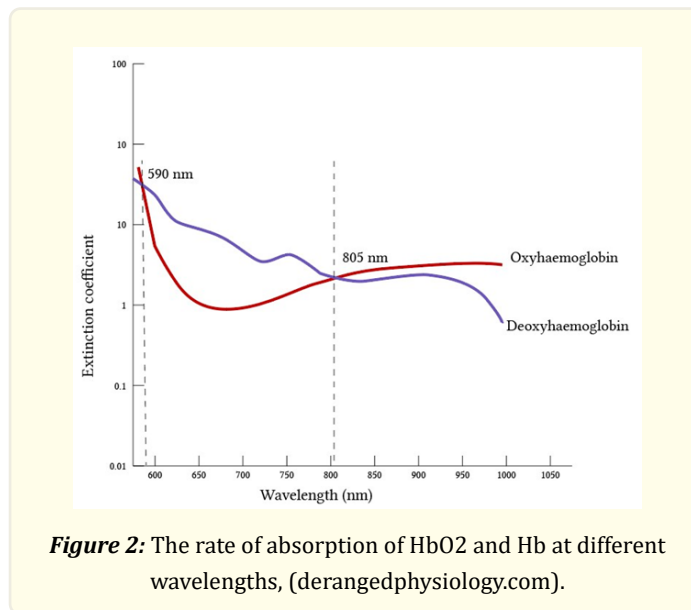
Fingertip pulse oximeters first launched to the market in 1995.

In 2007 FDA published a notice in Federal Register (Vol. 72, No. 138 / Thursday, July 19, 2007) titled "Draft Guidance for Industry and Food and Drug Administration Staff; Pulse Oximeters Premarket Notification Submissions [510(k)s]; Availability" for comment by October, 2007. Shortly after, FDA approved pulse oximeters appeared on the market.

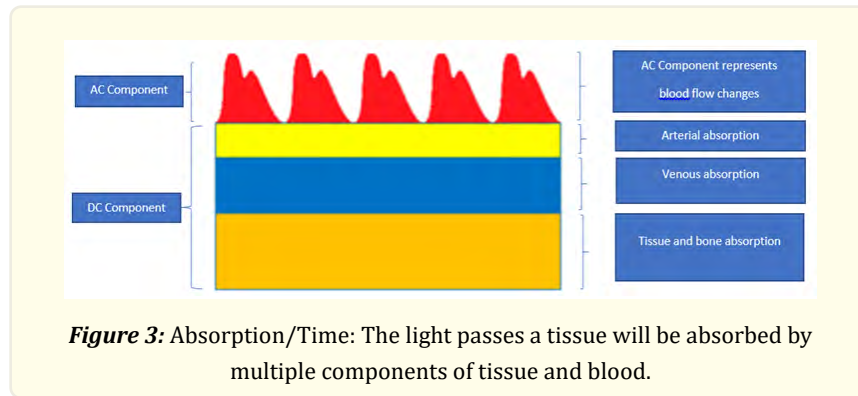
Recently: Pulse oximeter has become affordable and widely available for home use.

Technology

The principle of pulse oximetry is based on a modification of Beer Lambert's law, which relates the absorption of light is related to by concentration and optical properties at a specific light wavelength in the solute. Pulse oximetry is an application of Photoplethysmography (PPG), an optical noninvasive measurement technique used for the assessment and measuring blood volume changes in the micro vascular bed in tissues. Pulse oximetry is depending on the absorbance characteristics of hemoglobin in blood cells in the red and infra-red range. In the red region close to 660nm, oxyhemoglobin absorbs less light than deoxyhemoglobin and in the infrared region close to 940 nm deoxyhemoglobin absorbs less light that oxyhemoglobin. Pulse oximetry is based in measuring the amount of oxygen diluted in the blood that called oxygen saturation (SaO_2) in the blood. Its basic structure is obtained by combining two light-emitting diodes (LEDs) that operate at different wavelengths, along with a photodiode that receives light and connected to microprocessor. One of the LEDs operates in the visible red spectrum, about 660 nm, and the other for the infrared (IR) close to 940 nm. The tissue-reflected light from those LED is captured by a photodiode and its response is then used to calculate SaO_2 levels. In the arterial blood oxygenated hemoglobin (oxyhemoglobin, HbO_2) is found; its analogous, deoxygenated hemoglobin (Hb), circulates in the venous blood, both absorb different amounts of red and infrared light, with HbO_2 absorbing more infrared light than Hb. Figure 1 shows the spectral response of HbO_2 , Hb and the skin-tissue model that is commonly used for pulse oximetry [24-26].



The continuous component (DC), of the photodiode response represents the light absorbed by the tissue, the non-pulsatile arterial blood and the venous blood quantities. The variable component (AC) represents the pulsatile arterial blood component as shown in figure 3.



The ratio of absorption at the two wavelengths is used as a basis for pulse oximetry and can be calculate by equations (1) or (2).

$$R_{abs} = \frac{AC_{\lambda_1}/DC_{\lambda_1}}{AC_{\lambda_2}/DC_{\lambda_2}} \quad (1)$$

$$R_{abs} = \frac{\log_{10}(I_{AC\lambda_1})}{\log_{10}(I_{AC\lambda_2})} \quad (2)$$

If using equation (1) the SpO₂ rate is calculated trough the utilization of a stored conversion table with empirical formulas based on healthy patients’ measurements, so it can vary with the implementation. As a reference, a ratio of R_{abs}=0.5 would correspond to a SpO₂ of 100%; R_{abs}=1 would correspond to SpO₂ of 82% and Rabs=2.5 would correspond to a SpO₂ of 0%. Equation (2) uses only the AC component for SpO₂ calculations, here I_{AC} is the intensity of the light measured at 660 nm and 940 nm, 1 and 2 respectively [7, 27, 28].

In normal conditions, a healthy dental pulp will have a measurably high percentage of oxygen in its contents, as the dental pulp progress from a healthy condition to an inflammatory condition the oxygen levels start to decrease, note that this decrease in oxygen levels has not been verified in all inflammatory conditions. Several studies have tackled the issue of determining the reference oxygen saturation levels for healthy dental pulps in different clinical scenarios. From those studies it was obtained that: for maxillary central incisors the oxygen saturation varied from 79.31% to 94%; for maxillary lateral incisors 78.51% to 87.47%; canine 79.85% to 91%; premolars 86.2%. Also, premolars and molars were evaluated as a single group whose mean oxygen saturation values was recorded as 92.2% [25, 29].

The utilization of pulse oximetry as a noninvasive tool for human health monitoring is a relatively recent advance. In pulse oximeter, Red and IR wavelengths are used to trans-illuminate a tissue bed, the reflected portion of the signal is detected and processed. The processed signal is used to calculate pulse rate and oxygen saturation, as it varies with used wavelength and the characteristics of pulsatile blood circulation. Due to these characteristics, (detection of pulsatile blood absorbance), the technology appears to be suited for the detection of pulpal blood circulation, provided that is, that a sensor/sensor head that can be used in the tooth structure can be engineered [17, 19, 21, 30].

Advantages

1. Pulse oximetry offers an effective and objective method of evaluating dental pulp vitality [7].
2. In traumatized teeth where vitality blood supply remains functional but the nerve supply is damaged, is useful [7, 18].

3. Pulpal blood circulation can be detected independent of gingival blood circulation.
4. Dental pulp' pulse readings are reproducible [7].
5. Technological advances have made it possible to provide a smaller and cheaper device for routine use in dental offices.
6. Studies show that oxygen saturation is proportional to the severity of the disease and the degree of inflammation decrease oxygen saturation in the pulp tissue [18, 31].
7. Sensitivity, specificity, negative predictive value, and positive predictive value of pulse oximetry comparing to electrical and thermal tests confirmed in studies [1, 32].

Disadvantages

1. Despite technological advances, the distinction between background uptake associated with venous blood and tissue composition can be challenging.
2. Pulse oximetry probes should be designed for dental anatomy, especially since the oxygen saturation of the teeth is usually less than the patient's finger [7].

Comparison of laser Doppler flowmetry and pulse oximetry

To facilitate the comparison of pulse oximetry with laser Doppler flowmeter, we use the following comparison table so that we can easily understand the advantages and disadvantages of each against the other:

<i>Application</i>	<i>Laser Doppler Flowmetry YES/NO</i>	<i>Pulse oximetry YES/NO</i>
Non invasive	•	•
Reliable	•	•
Painless	•	•
Traumatized Monitoring	•	•
Children Monitoring	•	•
Cost Effective	•	•
Interferences of gingiva	•	•
Sensitive to probe location	•	•

Conclusion

The pulp sensitivity tests are not reliable based on nerve response; in cases such as trauma, or in pediatric patients who often cannot give a proper history, relying on the sensory response of neural tissues may lead to false results. The pulpal blood flow would be an objective assessment of pulpal blood circulation, a true indicator of pulp vitality. Optical devices studied, offered the advantages of being objective, noninvasive testing modalities, which result in greater patient acceptance and cooperation. Rapid advances in technology may quickly lead to more accurate and predictable tools for pulp vitality assessing.

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