Oxygen Level Measurement Techniques: Pulse Oximetry

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ABSTRACT - This paper reviews the architectural structure of the main types of pulse oximetry probes. There are two main oximeter types used nowadays. These are the transmittance probes and reflectance probes. The paper compares the design, complexity, reliability and accuracy, with different points of view each. The paper reviewed the various methods used in the measurement of oxygen levels in the human blood. The advantages and drawbacks of each oximeter method have been presented together with the accuracy and domains of use for each technique.

Keywords: Pulse Oximetry (PO), Oxygen Saturation (SpO_2), Oxygenated (O_2Hb), Transmittance Pulse Oximeter (TPO), Reflectance Pulse Oximeter (RPO).

المستخلص- تستعرض هذه الورقة الهيكل المعماري للأنواع الرئيسية من مقياس التأكسج. هناك نوعان مقياس التأكسج الرئيسية المستخدمة في الوقت الحاضر هي تحقيقات النفاذية وتحقيقات الانعكاس.تقارن الورقة من حيث التصميم ، التعقيد ، الموثوقية والدقة ، مع وجهات نظر مختلفة لكل منهما. الورقة ناقشت التعقيد و الموثوقية و الدقة للطرق المختلفة. تمت مناقشة المحاسن و المساوى المختلفة لطرق قياس نسبة الأوكسجين فى الدم.

INTORDUCTION

Oxygen (O_2) is one of the most important elements required to sustain life. Without oxygen, our health would suffer and people would die. Unhealthy or weak cells, due to improper metabolism, lose their natural immunity and are thus susceptible to viruses and lead the way to all kinds of serious health problems [1]. Human beings and all other organisms need oxygen to perform aerobic respiration. The Respiration is one of the key ways by which the body cells gain energy and food, and gets rid of junk and toxins. Oxygen transportation is performed through the circulatory system, deoxygenated blood enters the heart where it is pumped to the lungs to be oxygenated, and blood passes through the pulmonary alveoli where gas exchange (diffusion) occurs to replace the CO_2 to O_2.Figure 1 shows the pulmonary alveoli.

Healthy body should never fall below 95% oxygen saturation. Experienced clinicians would only notice signs of hypoxia (oxygen starvation) when patients become cyanosis; literally when their skin begins turning blue, with oxygen saturation going damagingly low at 85%. Once a patient starts losing oxygen, the doctors might have less than three minutes to prevent the risk of brain damage, heart failure and death.

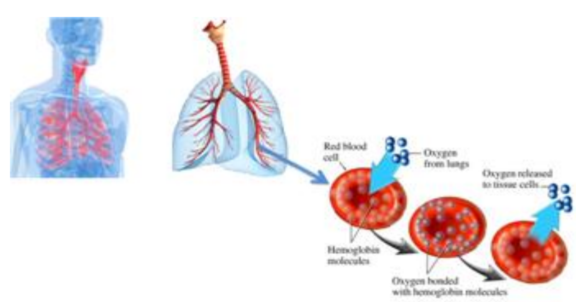

Figure 1: Pulmonary alveoli

A pulse oximeter is one of the most important monitoring tools in modern anesthesia practice. It is a non-invasive medical device that checks the level of oxygen in the bloodstream of patients and generates an alarm as soon as it detects unsafe changes [2]. It is widely used as a noninvasive, easy to use, and accurate method of estimation of peripheral blood flow, blood oxygen saturation, heart rate, and pulse amplitude. However, various probes and applications require specific signal conditioning, for example ear probe vs. finger probe or children vs. adult probe [3].

Principle of Oximetry:

Pulse oximeter is a non-invasive device, used for the measurement of the saturation of peripheral oxygen (SpO2). Oxygen saturation can defined as the amount of oxygen dissolved in blood, depending on the detection of oxygen rate in blood cell. It is useful in emergency department (ED), surgeries and intensive care units in the evaluation of patients with acute cardiopulmonary disorders such as chest trauma, bronchiolitis, asthma, heart failure, and chronic obstructive pulmonary disease.

The pulse oximeter contains light sensors. These are two LEDs (infrared and red) in addition to a photodiode that is placed between patient's body, such as a finger or earlobes. The two LEDs are paired and placed in a direction to enable the photodiode receive the light such that as they alternately transmit or reflect light through the anatomy depending on oximeter probe type. The photodiode is light detector (Photodiode or Transistor), it converts the received light that has not been absorbed or scattered in the anatomy to an analog electrical signal [4]. Figure 2 shows the schematic of the optical sensor.

The absorption spectra of HbO_2 and Hhb is measured using two wavelengths 660 nm (red light spectra) and 940 nm (infrared light spectra) [5]. Deoxygenated hemoglobin (Hb Xs) has a higher absorption at 660 nm and oxygenated hemoglobin (HbO2) has a higher absorption at 940 nm as shown on Figure 3.

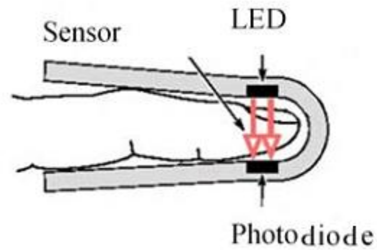

Figure 2: Structure of the optical sensor [5]

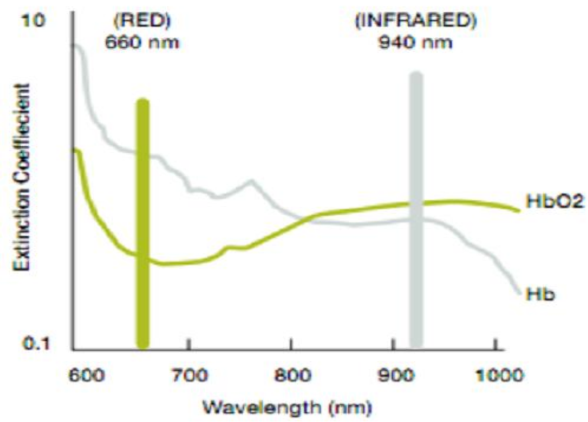

Figure 3: light absorption of the Hemoglobin [5]

This signal represents the light that has been absorbed by the anatomy and DC component represents the light absorption of the tissue, venous blood, and non-pulsatile arterial blood. The AC component represents the pulsatile arterial blood [5] [6], as shown on Figure 4.

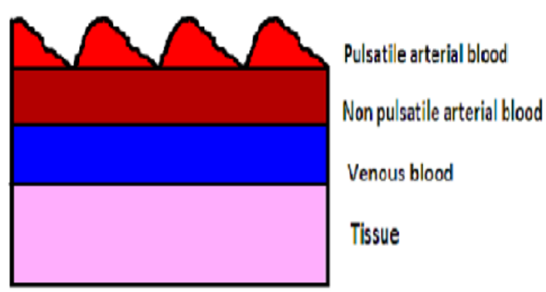

Figure 4: Light absorption diagram of body [5]

The pulse oximeter analyzes the light absorption of two wavelengths and calculates the absorption ratio using the following equation [5].

$$R = \frac{AC_{660} / DC_{660}}{AC_{940} / DC_{940}} \qquad (1)$$

Various types of oximeters based on the above facts and information have been proposed and built. One oximeter is called the transmittance pulse oximeter (TPO), the second one is called reflectance pulse oximeter (RPO). The difference is in the way the anatomy within the probe are positioned as shown on Figure 5. Both types are used clinically, though the in some cases, backpressure is preferable over the other.

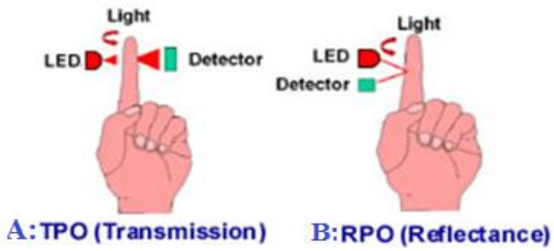

Figure 5: TPO vs. RPO.

Figure 6: Transmittance Pulse Oximeter (TPO)

Oximeters have been designed to use wavelengths in a relatively wide range. Most oximeters use near-infrared spectroscopy (NIRS) or pulse oximetry. However, visible light spectroscopy has also been used in [6].

Transmittance Pulse Oximeter (TPO):

A transmittance probe structure has two LEDs (Red and IR) on one side and a photodiode (light detector) on the other side. This type of oximeter can only be used on limited areas of the body. This is because some tissues of the patients should be inserted between the two LDSs. It is normally placed on a finger or ear as shown on Figure (6), and it's very easy to attach and remove. The light is emitted by the LEDs and then passes through tissue and blood vessels to be received by the photodiode. Some of the light would be absorbed by the tissue and the remaining part is fed to the photodiode, as shown on Figure 7. Transmittance probe is more commonly due to the simplicity of signal analysis, easy to use [7]. However, in some instances, when the transmission method is used, physiological conditions such as stress and temperature can affect the accuracy of pulse oximetry readings [8].

In general, transmittance probe signal are weaker from ears than fingers, except in the face of hypotension or peripheral vasoconstriction. Ear responses are faster .when compared to reflectance probe. There are fewer potential sensor sites, the response time can be long, and its performance is more adversely affected by ambient light, motion, and poor perfusion [8].

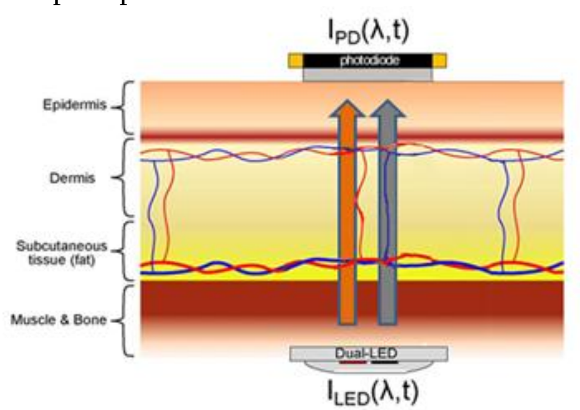

Figure 7: Signal transmitted via tissue to LED

Reflectance Pulse Oximeter (RPO):

A reflectance probe structure has the LEDs (Red and IR) and the photodiode (Light detector) on the same side. A reflectance oximeter has emitting and sensing diodes on a single surface. Therefore, they can be placed in anatomical location that doesn't require two surfaces in close proximity with a It must be placed over a point with underlying bones as placed on the forehead or the sternum as show on Figure 8.

Furthermore, their advantage is that, regardless of the patient's size or age (infants to very large adults) it's providing more accuracy and stable readings.

The light is emitted by the LEDs, passes through tissue and blood vessels, and then reflects off the bone, passes through the tissues again, that a significant amount of light will reflect off the skin in the reflectance setup, as show on Figure 9.Thus, reflectance probes have a high offset and a lower signal-to-noise ratio than the transmittance probes. However; reflectance setups also require a significantly greater amount of light. Thus, either more LEDs or more photodiodes need to be used (overhead, cost, complexity, hard analysis of signal) [7].

Figure 8: Reflectance Pulse Oximeter (RPO)

When compared and tested the reliability and accuracy of the two types of probes in patients undergoing vascular surgery for patients who suffer from vasoconstriction and peripheral vascular disease, the transmittance probe was failed to report accurate values while they reflectance forehead probe gave acceptable agreement than the older transmittance probe placed on the earlobe or finger. [9], [10].

The big disadvantage of reflectance oximeter lies in their propensity to be subject to contaminating sources of tissue e.g. arteries, pigmentation. In general, the reflectance oximeter is more sophisticated in design, requires more user skill to correctly apply the sensor and interpret the results, including waveform morphology. It can provide more parameters and has greater versatility than transmutation methods [8].

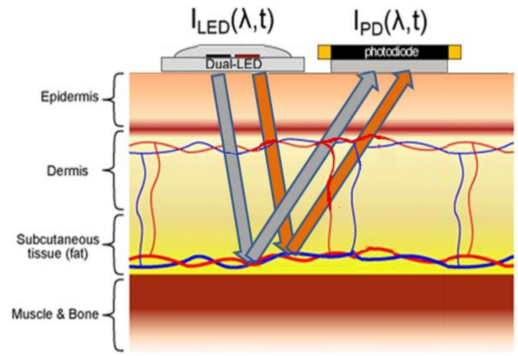

Figure 9: Signal reflected via tissue to LED

Network of Oximeter Sensors

For continuous mentoring of oxygen levels on certain patients, it becomes necessary to perform a continuous real-time check of the oxygen levels. A solution that has been proposed is to employ a network of sensors distributed on various parts of the body. Monitoring is performed via a dedicated microcontroller that assesses the local levels and monitors the overall body oxygen. Various types of alerts could be generated in case of low levels.

RESULTS

A number of patients were enrolled in the previous studies [9], [11]. The Patients with peripheral vascular disease undergoing vascular surgery under general anesthesia with both a transmittance finger probe and a reflectance forehead probe the values were simultaneously recorded. A comparison between SpO_2 measurements is obtained for the finger vs. the forehead and used the blood analysis using the Bland–Altman method as reference reading. This was obtained using a bias and precision of (+1.0 to +1.4) and (+2.5 to 4.8) %, respectively, and the limits of agreement ranged from −4.0 to 6.0%. The finger probe failed to give a value in a number of cases, and gave accurate values in other cases. The limits of agreement ranged from −8.0 to 10.9%. There were 15% outliers for the forehead probe and 32 % for the finger probe [9], [11].

Comparisons of the probes design matrix are shown in Table 1. As the attribute indicates, Forehead Reflectance probe design is more dependent on the blood flow. However, they are more expensive and difficult to use as they need more experience. While the Finger transmittances probe design has lower accuracy and dependable blood. However, it's more comfortable and commonly used.

Table 1: Design attribute with compare between finger and forehead probe

	Weight	Finger	Forehead
Cost	10%	7	7
Accuracy	250%	5.5	6.5
Ease of Use	20%	9	5.375
Range of Use	20%	8.5	7.625
Durability	25%	4.375	7.625
Total	100%	66.7	68.3

CONCLUSIONS

This paper has highlighted the importance and need of the accurate assessment of oxygen levels in the some patients. Prolonged low oxygen levels could be fatally dangerous. The paper reviewed the various methods used in the measurement of oxygen levels in the human blood. The advantages and drawbacks of each oximeter method have been presented together with the accuracy and domains of use for each technique.

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