Pulse oximetry - its idea, theory and future

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It had long been a challenging problem to measure SaO2 noninvasively and continuously. J. R. Squire solved the problem of how to measure both of incident light and transmitted light of the blood in the tissue. Using his idea E. H. Wood developed the first SaO2 monitor [1]. But his system had shortcomings for clinical use. For instance, in a long term monitoring, unintentional shifts in probe position cause to tell us false SaO2 value.

In December 1972, I noticed that the pulsation of tissue transmitted light reflects SaO2 value. This idea of pulse oximetry solved the shortcomings. We made up a pilot model and gave a presentation on it in 1974 [2]. It is my great pleasure that pulse oximetry is now considered indispensable in modern medicine. On the other hand, many new problems with performance of pulse oximetry have emerged. We believed only a multi-wavelength system can solve those problems. We constructed the theory of pulse oximetry and realized the multi-wavelength system. The system proved to solve many problems with pulse oximetry.

The pulse oximetry uses pulsation of transmitted light Li and obtains Φij corresponding to SaO2.

$$dAi=\log[(Li+dLi)/Li],\quad \Phi ij=dAi/dAj.$$

We noticed the theory of A. Schuster [3] can be used as the basis for theory of pulse oximetry. We noticed that the pulsation of tissue transmitted light is composed of arterial blood (a), venous blood (v), and pure tissue (t).

$$dAa=\sqrt{Ea(Ea+F)}*Hb*dDa,\quad dAv=\sqrt{Ev(Ev+F)}*Hb*dDv,\quad dAt=Zt*dDt.$$

Where $Ea=SaEo+(1-Sa)Er$ and $Ev=SvEo+(1-Sv)Er$. S is oxygen saturation. Eo and Er are extinction coefficient of oxy- and deoxy-hemoglobin, respectively. Hb is hemoglobin concentration. dD is pulsating thickness.

$$\Phi ij=dAi/dAj=(\sqrt{Eai(Eai+F)}+\sqrt{Evi(Evi+F)}*V+Exi)/(\sqrt{Eaj(Eaj+F)}+\sqrt{Evj(Evj+F)}*V+Exj).$$

Where $V=dDv/dDa$, and $Exi=Zti*dDt/(Hb*dDa)$. An approximation of Exi was applied: $Exi=AiEx2+Bi$. Where Ai and Bi were experimentally obtained.

When approximated that the tissue is only error factor, unknowns are Sa and Ex2. Three wavelengths 805nm, 875nm and 660nm were used. $\Phi 12=dA1/dA2$ and $\Phi 32=dA3/dA2$ were obtained and Sa was calculated as a solution of simultaneous equations. The correlation between SaO2 and SpO2 was improved with this system.

When venous blood also is considered, unknowns are Sa, Sv, V and Ex2. Five wavelengths 805nm, 875nm, 660nm, 700nm and 730nm were used. $\Phi 12=dA1/dA2$, $\Phi 32=dA3/dA2$, $\Phi 42=dA4/dA2$ and $\Phi 52=dA5/dA2$ were obtained and Sa was calculated. The motion artifact was eliminated without delay and flattening.

The 3rd error factor is the optics. Incident light scattering in the tissue causes light path differences depending on wavelength. To eliminate this error factor, a thin scattering plate on the incident side is necessary. To realize this idea, it is desirable to use a higher power LEDs.

The near-future pulse oximetry will show us its true nature of high-fidelity in measurement of SaO_2. It will play an increasingly important role in wide range of clinical phases.

Reference:

[1] Severinghaus JW, Astrup PB. (1987) “History of blood gas analysis.” International Anesthesiology Clinics. Winter 1987, 25(4). [2] Aoyagi T, Kishi M, Yamaguchi K, Watanabe S. (1974) Improvement of an earpiece oximeter. The 13th Annual Meeting of the Japan Society of MEBE pp 90-91 (Abstract in Japanese). [3] Schuster A. (1905) Radiation through a foggy atmosphere. Astrophysical Journal 21: pp1-22. [4] Aoyagi T.(2003) Pulse Oximeter: It’s Invention, Theory, and Future. Journal of Anesthesia (2003)17:259-266.