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(54) **METHOD FOR NON-INVASIVE SPECTROPHOTOMETRIC BLOOD OXYGENATION MONITORING**

VERFAHREN ZUR NICHT-INVASIVEN SPEKTROPHOTOMETRISCHEN ÜBERWACHUNG DER SAUERSTOFFSÄTTIGUNG DES BLUTES

METHODE DE SURVEILLANCE SPECTROPHOTOMETRIQUE NON EFFRACTIVE DE L'OXYGENATION SANGUINE

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- **BENNI P B ET AL: "A novel near-infrared spectroscopy (NIRS) system for measuring regional oxygen saturation" PROCEEDINGS OF THE IEEE 21ST ANNUAL NORTHEAST BIOENGINEERING CONFERENCE, 22 May 1995 (1995-05-22), pages 105-107, XP000557749 Cat. No.95CH35807 ISBN: 0-7803-2693-8**

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Description

BACKGROUND OF THE INVENTION

1. Technical Field.

[0001] This invention relates to methods for non-invasively determining biological tissue oxygenation in general, and to non-invasive methods utilizing near-infrared spectroscopy (NIRS) techniques in particular. 2. Background Information.

[0002] The molecule that carries the oxygen in the blood is hemoglobin. Oxygenated hemoglobin is called oxyhemoglobin (HbO_2) and deoxygenated hemoglobin is deoxyhemoglobin (Hb). Total hemoglobin is the summation of the two states of hemoglobin (Total Hb = HbO_2+ Hb), and is proportional to relative blood volume changes, provided that the hematocrit or hemoglobin concentration of the blood is unchanged. The mammalian cardiovascular system consists of a blood pumping mechanism (the heart), a blood transportation system (blood vessels), and a blood oxygenation system (the lungs). Blood oxygenated by the lungs passes through the heart and is pumped into the arterial vascular system. Under normal conditions, oxygenated arterial blood consists predominately of HbO_2. Large arterial blood vessels branch off into smaller branches called arterioles, which profuse throughout biological tissue. The arterioles branch off into capillaries, the smallest blood vessels. In the capillaries, oxygen carried by hemoglobin is transported to the cells in the tissue, resulting in the release of oxygen molecules ($HbO_2 \Rightarrow$ Hb). Under normal conditions, only a fraction of the HbO_2 molecules give up oxygen to the tissue, depending on the cellular metabolic need. The capillaries then combine together into venuoles, the beginning of the venous circulatory system. Venuoles then combine into larger blood vessels called veins. The veins further combine and return to the heart, and then venous blood is pumped to the lungs. In the lungs, deoxygenated hemoglobin Hb collects oxygen becoming HbO_2 again and the circulatory process is repeated.

[0003] Oxygen saturation is defined as:

$$O_2\ saturation\% = \frac{HbO_2}{(HbO_2 + Hb)} x\ 100\% \quad \text{(Eqn.1)}$$

In the arterial circulatory system under normal conditions, there is a high proportion of HbO_2 to Hb, resulting in an arterial oxygen saturation (defined as SaO_2 %) of 95-100%. After delivery of oxygen to tissue via the capillaries, the proportion of HbO_2 to Hb decreases. Therefore, the measured oxygen saturation of venous blood (defined as SvO_2 %) is lower and may be about 70%.

[0004] One spectrophotometric method, called pulse oximetry, determines arterial oxygen saturation (SaO_2) of peripheral tissue (i.e. finger, ear, nose) by monitoring pulsatile optical attenuation changes of detected light induced by pulsatile arterial blood volume changes in the arteriolar vascular system. The method of pulse oximetry requires pulsatile blood volume changes in order to make a measurement. Since venous blood is not pulsatile, pulse oximetry cannot provide any information about venous blood.

[0005] Near-infrared spectroscopy (NIRS) is an optical spectrophotometric method of continually monitoring tissue oxygenation that does not require pulsatile blood volume to calculate parameters of clinical value. The NIRS method is based on the principle that light in the near-infrared range (700 to 1,000 nm) can pass easily through skin, bone and other tissues where it encounters hemoglobin located mainly within micro-circulation passages; e.g., capillaries, arterioles, and venuoles. Hemoglobin exposed to light in the near infra-red range has specific absorption spectra that varies depending on its oxidation state; i.e., oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) each act as a distinct chromophore. By using light sources that transmit near-infrared light at specific different wavelengths, and measuring changes in transmitted or reflected light attenuation, concentration changes of the oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) can be monitored. The ability to continually monitor cerebral oxygenation levels is particularly valuable for those patients subject to a condition in which oxygenation levels in the brain may be compromised, leading to brain damage or death.

[0006] The apparatus used in NIRS analysis typically includes a plurality of light sources, one or more light detectors for detecting reflected or transmitted light, and a processor for processing signals that represent the light emanating from the light source and the light detected by the light detector. Light sources such as light emitting diodes (LEDs) or laser diodes that produce light emissions in the wavelength range of 700-1000nm at an intensity below that which would damage the biological tissue being examined are typically used. A photodiode or other light source detector is used to detect light reflected from or passed through the tissue being examined. The processor takes the signals from the light sources and the light detector and analyzes those signals in terms of their intensity and wave properties.

[0007] It is known that relative changes of the concentrations of HbO_2 and Hb can be evaluated using apparatus similar to that described above, including a processor programmed to utilize a variant of the Beer-Lambert Law, which

accounts for optical attenuation in a highly scattering medium like biological tissue. The modified Beer-Lambert Law can be expressed as:

$$A_\lambda = -\log\left(I / I_o\right)_\lambda = \alpha_\lambda * C * d * B_\lambda + G \quad \text{(Eqn.2)}$$

wherein "A_λ" represents the optical attenuation in tissue at a particular wavelength λ (units: optical density or OD); "I_o" represents the incident light intensity (units: W/cm^2); "I" represents the detected light intensity; "α_λ" represents the wavelength dependent absorption coefficlent of the chromophore (units: OD * cm^{-1} * μM^{-1}); "C" represents the concentration of chromophore (units: μM); "d" represents the light source to detector (optode) separation distance (units: cm); "B_λ" represents the wavelength dependent light scattering differential pathlength factor (unitless); and "G" represents light attenuation due to scattering within tissue (units: OD).

[0008] Absolute measurement of chromophore concentration (C) is very difficult because G is unknown or difficult to ascertain. However, over a reasonable measuring period of several hours to days, G can be considered to remain constant, thereby allowing for the measurement of relative changes of chromophore from a zero reference baseline. Thus, if time t_1 marks the start of an optical measurement (i.e., a base line) and time t_2 is an arbitrary point in time after t_1, a change in attenuation (ΔA) between t_1 and t_2 can be calculated, and variables G and I_o will cancel out providing that they remain constant.

[0009] The change in chromophore concentration ($\Delta C = C(t_2) - C(t_1)$) can be determined from the change In attenuation ΔA, for example using the following equation derived from the Beer-Lambert Law:

$$\Delta A = -\log\left(I_{t2} / I_{t1}\right)_\lambda \approx \alpha_\lambda * \Delta C * d * B_\lambda \quad \text{(Eqn.3)}$$

Presently known NIRS algorlthms that are designed to calculate the relative change In concentration of more than one chromophore use a multivariate form of Equation 2 or 3. To distinguish between, and to compute relative changes in, oxyhemoglobin (ΔHbO_2) and deoxyhemoglobin (ΔHb), a minimum of two different wavelengths are typically used. The concentration of the HbO_2 and Hb within the examined tissue is determined in μmoles per liter of tissue (μM).

[0010] The above-described NIRS approach to determining oxygen saturation levels is useful, but it is limited in that it only provides information regarding a change in the level of blood oxygen saturation, within the tissue. It does not provide a means for determining the total level of blood oxygen saturation within the biological tissue.

[0011] At present, information regarding the relative contributions of venous and arterial blood within tissue examined by NIRS is either arbitrarily chosen or is determined by invasive sampling of the blood as a process independent from the NIRS examination. For example, It has been estimated that NIRS examined brain tissue consists of blood comprising from about 60 to 80% venous to about 20 to 40% arterial blood. Blood samples from catheters placed in venous drainage sites such as the internal jugular vein, jugular bulb, or sagittal sinus have been used to evaluate NIRS measurements. It has been estimated in animal studies that NIRS interrogated tissue consists of a mixed vascular bed with a venous-to-arterial ratio of about 2:1 as determined from multiple linear regression analysis of sagittal sinus oxygen saturation ($SssO_2$) and carotid artery oxygen saturation (SaO_2) in comparison to NIRS measured ΔHb and ΔHbO_2. An expression representing the mixed venous / arterial oxygen saturation ($SmvO_2$) in NIRS examined tissue is shown by the equation:

$$SmvO_2 = Kv * SvO_2 + Ka * SaO_2 \quad \text{(Eqn.4)}$$

where "SvO_2" represents venous oxygen saturation; "SaO_2" represents arterial oxygen saturation; and Kv and Ka are the weighted venous and arterial contributions respectively, with Kv + Ka = 1. The parameters Kv and Ka may have constant values, or they may be a function of SvO_2 and SaO_2. Determined oxygen saturation from the internal jugular vein ($SijvO_2$), jugular bulb ($SjbO_2$), or sagittal sinus ($SssO_2$) can be used to represent SvO_2. Therefore, the value of each term in Equation 4 is empirically determined, typically by discretely sampling or continuously monitoring and subsequently evaluating patient arterial and venous blood from tissue that the NIRS sensor is examining, and using regression analysis to determine the relative contributions of venous and arterial blood independent of the NIRS examination.

[0012] What is needed, therefore, is a method for non-invasively determining the level of oxygen saturation within biological tissue that can determine the total oxygen saturation level rather than a change in level; a method that provides

calibration means to account for light attenuation due to scattering within tissue (G); and a method that can non-invasively distinguish the contribution of oxygen saturation attributable to venous blood and that which is attributable to arterial blood.

[0013] It is, therefore, an object of the present invention to provide a method for non-invasively determining the total level of blood oxygen saturation within biological tissue. According to the present invention there is provided a method as defined by claim 1. The features of the preamble to claim 1 are known from Benni et al (XP557749) cited above.

[0014] It is a further object of the present invention to provide a method that provides calibration means to account for light attenuation due to scattering within tissue, light attenuation due to fixed tissue absorbers, and light attenuation due to variability between light measuring apparatuses.

[0015] It is a still further object of the present invention to provide a method that can non-invasively distinguish between the contribution of oxygen saturation attributable to venous blood and that attributable to arterial blood.

[0016] A method for non-invasively determining the blood oxygen saturation level within a subject's tissue is provided that utilizes a near infrared spectrophotometric (NIRS) sensor capable of transmitting a light signal into the tissue of a subject and sensing the light signal once it has passed through the tissue via transmittance or reflectanoe. The method includes the step of determining attenuation of the light signal as the sum of: (I) attenuation attributable to deoxyhemoglobin; (II) attenuation attributable to oxyhemoglobin; and (iii) attenuation attributable to light scattering within the subject's tissue. The present method also makes it possible to account for attenuation attributable to fixed or constant light absorbing biological tissue components, and attenuation attributable to variable characteristics of the sensor. By determining differential attenuation as a function of wavelength; the attenuation attributable to tissue light scattering characteristics, fixed light absorbing components, and measuring apparatus characteristics are mathematically cancelled out or minimized relative to the attenuation attributable to deoxyhemoglobin, and attenuation attributable to oxyhemoglobin.

[0017] In order to account for the resulting minimized differential attenuation attributable to tissue light scattering characteristics, fixed light absorbing components, Previous attempts to determine quantitative tissue oxygen saturation levels have been described in Benni P B et al 'A novel near-infrared spectroscopy (NIRS) system for measuring regional oxygen saturation' PROCEEDINGS IEEE 21st ANNUAL NE BIOENGINEERING CONFERENCE, Cat.# 95CH35807, 1995, pages 105-107, XP557749, and in US 5 902 235 A and EP 0 760 476 A2. and measuring apparatus characteristics, each of the parameters must be measured or calibrated out. Since direct measurement is difficult, calibration to empirically determined data combined with data developed using the NIRS sensor is performed by using regression techniques. The empirically determined data is collected at or about the same time the data is developed with the NIRS sensor. Once the calibration parameters associated with attenuation attributable to tissue light scattering characteristics, fixed light absorbing components, and measuring apparatus characteristics have been determined, the NIRS sensor can be calibrated.

[0018] The calibrated sensor can then be used to accurately and non-invasively determine the total oxygen saturation level in the original subject tissue or other subject tissue. In addition, if the separation distance ("d") between the light source to the light detector is known or is determinable, and if the value of "B_λ", which represents the wavelength dependent light scattering differential pathlength factor, is known, then the total amount of concentrations of deoxyhemoglobin (Hb) and oxyhemoglobin (HbO_2) within the examined tissue can be determined using the present method and apparatus.

[0019] The calibrated sensor can be used subsequently to calibrate similar sensors without having to invasively produce a blood sample. Hence, the present method and apparatus enables a non-invasive determination of the blood oxygen saturation level within tissue. For example, an operator can create reference values by sensing a light signal or other reference medium using the calibrated sensor. The operator can then calibrate an uncalibrated sensor by sensing the same light signal or reference medium, and subsequently adjusting the uncalibrated sensor into agreement with the calibrated sensor. Hence, once a reference sensor is created, other similar sensors can be calibrated without the need for invasive procedure.

[0020] There are, therefore, several advantages provided by the present method. Those advantages include: 1) a practical non-invasive method for determining oxygen saturation within tissue that can be used to determine the total blood oxygen saturation within tissue as opposed to a change in blood oxygen saturation; 2) a calibration method that accounts for light attenuation due to scattering within tissue (G), fixed tissue absorbers (F), and measuring apparatus variability (N); and 3) a practical non-invasive method and apparatus for determining oxygen saturation within tissue that can distinguish between the contribution of oxygen saturation attributable to venous blood and that saturation attributable to arterial blood.

[0021] In an alternative embodiment, aspects of the above-described methodology are combined with pulse oximetry techniques to provide a non-invasive method of distinguishing between blood oxygen saturation within tissue that is attributable to venous blood and that which is attributable to arterial blood. Pulse oximetry is used to determine arterial oxygen saturation, and the arterial oxygen saturation is, in turn, used to determine the venous oxygen saturation.

[0022] These and other objects, features, and advantages of the present invention method will become apparent in light of the detailed description of the invention provided below and the accompanying drawings. The methodology and apparatus described below constitute a preferred embodiment of the underlying invention and do not, therefore, constitute

all aspects of the invention that will or may become apparent by one of skill in the art after consideration of the invention disclosed overall herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG.1 is a diagrammatic representation of a NIRS sensor placed on a subject's head.
[0024] FIG.2 is a diagrammatic representation of a NIRS sensor.
[0025] FIG.3 is a diagrammatic view of a NIRS sensor.
[0026] FIG.4 is a block diagram of the present methodology for calibrating a NIRS sensor.
[0027] FIG.5 is a graph showing an exemplary plot of absorption coefficient vs. wavelength.

DETAILED DESCRIPTION THE INVENTION

[0028] The present method for non-invasively determining the blood oxygen saturation level within a subject's tissue is provided that utilizes a near infrared spectrophotometric (NIRS) sensor that includes a transducer capable of transmitting a light signal into the tissue of a subject and sensing the light signal once it has passed through the tissue via transmittance or reflectance. The present method and apparatus can be used with a variety of NIRS sensors. The NIRS sensor described below which is the subject of U.S. Patent No. 6,503,418. is a preferred NIRS sensor. The present method is not limited to use with this preferred NIRS sensor, however.

[0029] Referring to FIGS. 1-5, the preferred NIRS sensor includes a transducer portion 10 and processor portion 12. The transducer portion 10 includes an assembly housing 14 and a connector housing 16. The assembly housing 14, which is a flexible structure that can be attached directly to a subject's body, includes one or more light sources 18 and a light detector 20. A disposable adhesive envelope or pad is used for mounting the assembly housing 14 easily and securely to the subject's skin. Light signals of known but different wavelengths from the light sources 18 emit through a prism assembly 22. The light sources 18 are preferably laser diodes that emit light at a narrow spectral bandwidth at predetermined wavelengths. In one embodiment, the laser diodes are mounted within the connector housing 16. The laser diodes are optically interfaced with a fiber optic light guide to the prism assembly 22 that is disposed within the assembly housing 14. In a second embodiment, the light sources 18 are mounted within the assembly housing 14. A first connector cable 26 connects the assembly housing 14 to the connector housing 16 and a second connector cable 28 connects the connector housing 16 to the processor portion 12. The light detector 20 includes one or more photodiodes. The photodiodes are also operably connected to the processor portion 12 via the first and second connector cables 26,28. The processor portion 12 includes a processor for processing light intensity signals from the light sources 18 and the light detector 20.

[0030] The processor utilizes an algorithm that characterizes a change in attenuation as a function of the difference in attenuation between different wavelengths. The present method advantageously accounts for but minimizes the attenuation effects of the scattering variable "G", pathlength B*d, and the absorption "F" due to other components present in biological tissue (i.e. bone, water, skin pigmentation, etc.) that have a relatively flat or very low absorption spectra over the measured wavelength range. In addition, the present method accounts for any offset attenuation "N" due to the characteristics of the sensor that may or may not be wavelength independent. The present method algorithm can be expressed as:

$$A_{\lambda 1} - A_{\lambda 2} = \Delta A_{\lambda 1 - \lambda 2} = \Delta A_{\lambda 12} \qquad \text{(Eqn. 5)}$$

where $A_{\lambda 1}$ and $A_{\lambda 2}$ are in the form of Equation 6 below which is a modified version of Equation 2 that accounts for attenuation due to "F" and "N":

$$A_{\lambda} = -\log\left(I / I_o\right)_{\lambda} = \alpha_{\lambda} * C * d * B_{\lambda} + G + F + N \quad \text{(Eqn.6)}$$

Substituting Equation 6 into Equation 5 for $A_{\lambda 1}$ and $A_{\lambda 2}$, the terms "F" and "N" within Equation 5 are subtracted out, provided they represent constant light absorption over the measurement wavelengths and provided the same sensor is used to sense the light signal at the various wavelengths. Therefore, in the case where the differential pathlength factor B is wavelength independent, then $\Delta A_{\lambda 12}$ can be expressed as:

$$\Delta A_{\lambda 12} = \mathbf{log}[(I_{\lambda 2} / Io_{\lambda 2})/(I_{\lambda 1} / Io_{\lambda 1})] = \Delta \alpha_{c\lambda 12}\, cdB + \Delta G_{\lambda 12} \quad \text{(Eqn 7)}$$

and rewritten in expanded form:

$$\Delta A_{\lambda 12} = \left(\alpha_{Hb\lambda 1} - \alpha_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha_{HbO_2\lambda 1} - \alpha_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G_{\lambda 12} \quad \text{(Eqn.8)}$$

Alternatively, the differential pathlength factor "B" may be wavelength dependent. In this case, it is desirable to separate B_1 into two components:

$$B_\lambda = B * k_\lambda \quad \text{(Eqn.9)}$$

The parameter B is determined at one specific wavelength and the parameter k_λ represents how B would change at other wavelengths. To continue with the mathematical derivations, it is then desirable to combine the pathlength wavelength dependent parameter k_λ to α_λ:

$$\alpha'_\lambda = \alpha_\lambda * k_\lambda \quad \text{(Eqn.10)}$$

The parameter α'_λ represents the absorption coefficient α_λ adjusted by pathlength wavelength dependent parameter k_λ. Incorporation of these modifications into Equation 7 results in the following:

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G_{\lambda 12} \quad \text{(Eqn.11)}$$

where:

$$\left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB$$

represents the attenuation attributable to Hb;

$$\left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB$$

represents the attenuation attributable to HbO_2; and

$$\Delta G_{\lambda 12}$$

represents the attenuation attributable to light scattering within tissue (G).

[0031] In another alternative case, the light absorption due to the fixed tissue absorbers (F), and sensor variability (N) may not be constant over the measuring wavelengths. In this case, differential attenuation as a function of wavelength would result in the parameters $\Delta F_{\lambda 12}$ and $\Delta N_{\lambda 12}$, to be included in Equation 7 or Equation 11.

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G_{\lambda 12} + \Delta F_{\lambda 12} + \Delta N_{\lambda 12}$$

(Eqn.12)

The parameter $\Delta N_{\lambda 12}$, does not change in magnitude for a particular NIRS sensor. The parameter $\Delta F_{\lambda 12}$, by definition, would be the result of differential attenuation due to components that have a relatively flat or very low absorption spectra over the measured wavelength range, and therefore would be a very small and relatively constant value when compared to the differential attenuation due to hemoglobin. Thus, $\Delta F_{\lambda 12}$ can be seen as a fixed absorber error correcting parameter in Equation 12. Therefore, these parameters then can be summed together by superposition to become $\Delta G'_{12}$:

$$\Delta G'_{\lambda 12} = \Delta G_{\lambda 12} + \Delta F_{\lambda 12} + \Delta N_{\lambda 12} \quad \text{(Eqn. 13)}$$

Incorporation of these modifications into Equation 12 results in the following:

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G'_{\lambda 12} \quad \text{(Eqn.14)}$$

[0032] Note that if $\Delta G_{\lambda 12} << G_{\lambda 1}$ and $G_{\lambda 2}$, the effect of G is minimized within Equation 11, in contrast with the effect of G within Equation 2, at the cost of utilizing one more wavelength to determine Hb and HbO_2. Thus, a minimum of three different wavelengths is needed to determine Hb and HbO_2. Also in the alternative case, $\Delta G'_{\lambda 12}$ minimizes the effects of light attenuation due to scattering within tissue (G), fixed tissue absorbers (F), and sensor variability (N), at the same cost of utilizing one more wavelength.

[0033] The multivariate form of Equation 11 or 14, after mathematical manipulation, is used to determine HbO_2 and Hb with three different wavelengths:

$$\begin{bmatrix} \Delta A_{\lambda 12} - \Delta G'_{\lambda 12} \\ \Delta A_{\lambda 13} - \Delta G'_{\lambda 13} \end{bmatrix} (dB)^{-1} = \begin{bmatrix} \Delta\alpha'_{Hb\lambda 12} \Delta\alpha'_{HbO_2\lambda 12} \\ \Delta\alpha'_{Hb\lambda 13} \Delta\alpha'_{HbO_2\lambda 13} \end{bmatrix} \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix} \quad \text{(Eqn.15)}$$

Rearranging and solving for HbO_2 and Hb, simplifying the $\Delta\alpha'$ matrix into $[\Delta\alpha']$:

$$\begin{bmatrix} \Delta A_{\lambda 12} \\ \Delta A_{\lambda 13} \end{bmatrix} [\Delta\alpha']^{-1} (dB)^{-1} - \begin{bmatrix} \Delta G'_{\lambda 12} \\ \Delta G'_{\lambda 13} \end{bmatrix} [\Delta\alpha']^{-1} (dB_\lambda)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix} \quad \text{(Eqn.16)}$$

and rewritten into:

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix} (dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix} (dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix} \quad \text{(Eqn.17)}$$

The parameters A_{Hb} and A_{HbO2} represent the product of the matrices $[\Delta A_\lambda]$ and $[\Delta\alpha']^{-1}$ and the parameters Ψ_{Hb} and Ψ_{HbO2} represent the product of the matrices $[\Delta G'_\lambda]$ and $[\Delta\alpha']^{-1}$. To determine the level of cerebral blood oxygen saturation ($CrSO_2$), Equation 17 is rearranged using the form of Equation 1 and is expressed as follows:

$$CrSO_2\% = \frac{\left(A_{HbO_2} - \Psi_{HbO_2}\right)}{\left(A_{HbO_2} - \Psi_{HbO_2} + A_{Hb} - \Psi_{Hb}\right)} * 100\% \quad \text{(Eqn.18)}$$

Note that the pathlength *d*B* cancels out in the manipulation from Equation 17 to Equation 18.

[0034] The value for $CrSO_2$ is initially determined from $SmvO_2$ using Equation 4 and the empirically determined values for SvO_2 and SaO_2. The empirically determined values for SvO_2 and SaO_2 are based on data developed by discrete sampling or continuous monitoring of the subject's blood performed at or about the same time as the sensing of the tissue with the sensor. The temporal proximity of the NIRS sensing and the development of the empirical data helps assure accuracy. The initial values for Kv and Ka within Equation 4 are clinically reasonable values for the circumstances at hand. The values for A_{HbO2} and A_{Hb} are determined mathematically using the values for Io_λ and I_λ for each wavelength sensed with the NIRS sensor (e.g., using Equation 2 or 6). The calibration parameters Ψ_{Hb} and T_{HbO2}, which account for the effects of light attenuation due to scattering within tissue (G), fixed tissue absorbers (F), and measuring apparatus variability (N), are then determined using Equation 18 and non-linear regression techniques by correlation to different weighted values of SvO_2 and SaO_2; i.e., different values of Ka and Kv. Statistically acceptable values of Kv and Ka and Ψ_{Hb} and Ψ_{HbO2} are converged upon using the non-linear regression techniques. Experimental findings show that after proper selection of Ka and Kv, the calibration parameters Ψ_{Hb} and Ψ_{HbO2} are constant within a statistically acceptable margin of error for an individual NIRS sensor used to monitor brain oxygenation on different human subjects. In other words, once the sensor is calibrated it can be used on various human subjects and produce accurate information for each human subject.

[0035] In the determination of the $CrSO_2$ percentage, the photon pathlength "d*B" cancels out. If, however, the photon pathlength is known or estimated, then the determination of the total value of Hb and/or HbO_2 is possible. For example, if a value for pathlength "d*B" is input into Equation 17 along with the calibration values Ψ_{Hb} and Ψ_{HbO2}, then the total value of Hb and/or HbO_2 can be calculated. The light source to detector separation (optode) distance parameter "d" in the pathlength calculation is a measurable value and can be made constant by setting a fixed distance between light source to detector in the NIRS sensor design. Alternatively, the parameter "d" can be measured once the optodes are placed on the subject by use of calipers, ruler, or other distance measurement means. The pathlength differential factor "B" is more difficult to measure and requires more sophisticated equipment. From a large data set of measured neonatal and adult head differential pathlength factor values, an estimation of the value of "B" can be determined within a statistically acceptable margin of error. Substitution of these predetermined values of "B" into Equation 17 results in the determination of the total values of Hb and HbO_2.

[0036] An alternative method of determining total values of Hb and HbO_2 combines Equation 3 and Equation 17 together. The multivariate form of Equation 3 is shown below:

$$\begin{bmatrix} -\log(I_{t2}/I_{t1})_{\lambda 1}/(d*B_{\lambda 1}) \\ -\log(I_{t2}/I_{t1})_{\lambda 2}/(d*B_{\lambda 2}) \\ -\log(I_{t2}/I_{t1})_{\lambda 3}/(d*B_{\lambda 3}) \end{bmatrix} = \begin{bmatrix} \alpha_{Hb\lambda 1} & \alpha_{HbO_2\lambda 1} \\ \alpha_{Hb\lambda 2} & \alpha_{HbO_2\lambda 2} \\ \alpha_{Hb\lambda 3} & \alpha_{HbO_2\lambda 3} \end{bmatrix} * \begin{bmatrix} \Delta Hb \\ \Delta HbO_2 \end{bmatrix} \quad \text{(Eqn.19)}$$

At time $t = t_1$, the values of ΔHb and ΔHbO_2 are zero. Applying Equation 17, and knowing the calibration values of Ψ_{Hb} and Ψ_{HbO2} at a predetermined differential pathlength factor "B" and optode separation "d", the total absolute values of Hb and HbO_2 are determined at time $t = t_1$, which are represented by $[Hb]_{t1}$ and $[HbO_2]_{t1}$ respectively. At time $t=t_2$, the values of ΔHb and ΔHbO_2 are then determined using Equation 19. The total values of Hb and HbO_2 are then determined at time $t = t_2$ using the following equations:

$$[Hb]_{t_2} = \Delta Hb(t_2) + [Hb]_{t_1} \quad \text{(Eqn.20)}$$

$$[HbO_2]_{t_2} = \Delta HbO_2(t_2) + [HbO_2]_{t_1} \quad \text{(Eqn.21)}$$

Equations 20 and 21 are valid only if all the shared parameters in Equations 17 and 19 are exact. Reduced to practice, the advantage of combining Equations 17 and 19 result in improved signal to noise ratio (SNR) in the calculation of the total values for Hb and HbO_2. Conversely, improved SNR in the calculation of $CrSO_2$ is also obtained from the following expression:

$$CrSO_2(t_2) = \frac{[HbO_2]_{t_2}}{([HbO2]_{t_2} + [Hb]_{t_2})} * 100\% \quad \text{(Eqn.22)}$$

[0037] After the calibration parameters Ψ_{Hb} and Ψ_{HbO2} are determined using the above-described methodology for an individual NIRS sensor, this particular sensor is said to be calibrated. A calibrated NIRS sensor affords accurate measurement of total tissue oxygen saturation, $CrSO_2$, by non-invasive means. The calibrated sensor can be used thereafter on any human patient, including adults and neonates. Although the present method is described above in terms of sensing blood oxygenation within cerebral tissue, the present method and apparatus are not limited to cerebral applications and can be used to determine blood oxygenation within tissue found elsewhere within the subject's body.

[0038] According to an additional aspect of the present invention, the above-described method can also be used to establish a calibrated "reference" sensor that can be used to calibrate similar sensors through the use of a phantom sample (also referred to as a "reference sample"). The phantom sample has optical characteristics that are similar to the tissue being examined by the NIRS sensor. The calibrated reference NIRS sensor is used to sense the phantom sample and produce reference values. Similar, but uncalibrated, NIRS sensors can thereafter be calibrated by sensing the same phantom sample and adjusting either the hardware of the uncalibrated sensor or the output of the uncalibrated sensor until the output of the uncalibrated sensor agrees with the reference values produced by the calibrated reference sensor. Therefore, the calibration parameters Ψ_{Hb} and Ψ_{HbO2} for the uncalibrated sensor would be determined from the phantom sample. This technique makes it unnecessary to calibrate each new sensor in the manner described above, and thereby provides a relatively quick and cost effective way to calibrate NIRS sensors.

[0039] Besides Hb and HbO_2, other biological constituents of interest (e.g., cytochrome aa_3, etc.) could be determined using the multivariate forms of equations 2, 3, 6 or 7. For each additional constituent to be determined, an additional measuring wavelength will be needed.

[0040] In an alternative embodiment, the above-described methodology can be combined with pulse oximetry techniques to provide an alternative non-invasive method of distinguishing between oxygen saturation attributable to venous blood and that attributable to arterial blood. As demonstrated by Equation 4, $SmvO_2$ is determined by the ratio of venous oxygen saturation SvO_2 and arterial oxygen saturation SaO_2. A calibrated NIRS sensor affords accurate measurement of total tissue oxygen saturation, $CrSO_2$, by using regression techniques by correlation to mixed venous oxygen saturation $SmvO_2$. Therefore, the following expression will result:

$$CrSO_2 \approx SmvO_2 = Kv * SvO_2 + Ka * SaO_2 \quad \text{(Eqn. 23)}$$

Non-invasive pulse oximetry techniques can be used to determine the arterial oxygen saturation (SaO_2) of peripheral tissue (i.e. finger, ear, nose) by monitoring pulsatile optical attenuation changes of detected light induced by pulsatile arterial blood volume changes in the arteriolar vascular system, Arterial blood oxygen saturation determined by pulse oximetry is clinically denoted as SpO_2. If NIRS monitoring and pulse oximetry monitoring are done simultaneously and SpO_2 is set equal to SaO_2 in Equation 23, then venous oxygen saturation can be determined from the following expression:

$$SvO_2 = \frac{CrSO_2 - (Ka * SpO_2)}{Kv} \quad \text{(Eqn. 24)}$$

For the brain, venous oxygen saturation SvO_2 would be determined from internal jugular vein ($SijvO_2$), jugular bulb ($SjbO_2$), or sagittal sinus ($SssO_2$) and the parameters Ka and Kv would be empirically determined during the calibration of the NIRS sensor. Under most physiological conditions, SpO_2 is representative of brain arterial oxygen saturation SaO_2. Therefore, depending on which venous saturation parameter was used to calibrate the NIRS sensor, this clinically Important parameter (i.e., $SijvO_2$, $SjbO_2$, or $SssO_2$) can be determined by Equation 24 by non-invasive means.

[0041] Since many changes and variations of the disclosed embodiment of the invention may be made without departing

from the inventive concept, it is not intended to limit the Invention otherwise than as required by the appended claims.

Claims

1. A method for non-invasively determining the total blood oxygen saturation level within a subject's tissue using a near infrared spectrophotometric sensor, the sensor having a transducer portion (10) and a processor portion (12), said method comprising the steps of:

   transmitting a light signal into the subject's tissue at a predetermined first intensity using the sensor, wherein the transmitted light signal includes a first wavelength, a second wavelength, and a third wavelength; and
   sensing a second intensity of the light signal, using the sensor, along the first, second, and third wavelengths after the light signal travels through the subject; **characterised in that**:

      the sensor is calibrated using empirical data collected at or about the same time as the sensing of the tissue with the sensor to account for light signal attenuation resulting from light signal scattering within the subject's tissue and one or both of light signal attenuation due to fixed tissue absorbers and sensor variability; and by:

         determining an attenuation of the light signal for each of the first, second, and third wavelengths using the predetermined first intensity and the sensed second intensity of the first, second, and third wavelengths;
         determining a difference in attenuation of the light signal between the first wavelength and the second wavelength, and between the first wavelength and the third wavelength; and
         determining the blood oxygen saturation level within the subject's tissue using the difference in attenuation between the first wavelength and the second wavelength, and the difference in attenuation between the first wavelength and the third wavelength.

2. The method of claim 1, wherein the sensor is calibrated using equation:

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2.$$

3. The method of claim 2, further comprising the steps of:

   determining a blood oxygen saturation level attributable to arterial blood within the subject's tissue using a pulse oximetry technique; and
   determining a blood oxygen saturation level attributable to venous blood within the subject's tissue using the equation:

$$SvO_2 = \frac{CrSO_2 - (Ka * SpO_2)}{Kv}.$$

4. The method of claim 2, wherein the sensor is calibrated by using empirical data to determine a first calibration constant and a second calibration constant.

5. The method of claim 1, further comprising the steps of:

   determining a first calibration constant and a second calibration constant using empirical data developed from the subject at or about the same time as when the sensing occurs; and
   determining the blood oxygen saturation level within the subject's tissue using the difference in attenuation between the first wavelength and the second wavelength, and the difference in attenuation between the first wavelength and the third wavelength, and the first calibration constant and the second calibration constant.

6. The method of claim 1, further comprising the steps of:

determining a first calibration constant and a second calibration constant using empirical data developed from the subject at or about the same time as when the sensing occurs; and
calibrating the sensor using the first calibration constant and the second calibration constant.

7. The method of claim 5 or 6, wherein the empirical data is collected by discretely sampling a venous blood source and an arterial blood source from the subject.

8. The method of claim 5 or 6, wherein the empirical data is collected by continuously monitoring a venous blood source and an arterial blood source from the subject.

9. The method of claim 5 or 6, wherein the sensor is calibrated using equation:

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2.$$

10. The method of any of claims 4-9, wherein the step of determining the blood oxygen saturation level within the subject's tissue utilizes the equation:

$$CrSO_2\% = \frac{\left(A_{HbO_2} - \Psi_{HbO_2}\right)}{\left(A_{HbO_2} - \Psi_{HbO_2} + A_{Hb} - \Psi_{Hb}\right)} * 100\%$$

where Ψ_{HbO2} represents the first calibration constant, Ψ_{Hb} represents the second calibration constant, A_{HbO2} represents a difference in attenuation of light signal attributable to oxyhemoglobin, and A_{Hb} represents a difference in attenuation of light signal attributable to deoxyhemoglobin.

11. The method of claim 10, further comprising the steps of:

determining a photon pathlength d*B; and
determining the concentration of oxyhemoglobin and deoxyhemoglobin within the subject's tissue using the first and second calibration constants.

12. The method of claim 11, wherein the concentration of oxyhemoglobin and deoxyhemoglobin within the subject's tissue are determined using the equation

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix} (dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix} (dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix}.$$

13. The method of any preceding claim, wherein the step of determining a difference in attenuation of the light signal between the first wavelength and the second wavelength utilizes the equation:

$$\Delta A_{\lambda 12} = \log\left[\left(I_{\lambda 1} / Io_{\lambda 1}\right) * \left(I_{\lambda 2} / Io_{\lambda 2}\right)\right] = \Delta\alpha_{c\lambda 12} cdB + \Delta G_{\lambda 12}$$

and the step of determining a difference in attenuation of the light signal between the first wavelength and the third wavelength utilizes the equation:

$$\Delta A_{\lambda 13} = \log\left[\left(I_{\lambda 1} / Io_{\lambda 1}\right) * \left(I_{\lambda 3} / Io_{\lambda 3}\right)\right] = \Delta\alpha_{c\lambda 13} cdB + \Delta G_{\lambda 13} .$$

14. The method of any preceding claim, wherein the step of determining a difference in attenuation of the light signal between the first wavelength and the second wavelength utilizes the equation:

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G_{\lambda 12}$$

and the step of determining a difference in attenuation of the light signal between the first wavelength and the third wavelength utilizes the equation:

$$\Delta A_{\lambda 13} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 3}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 3}\right)[HbO_2]dB + \Delta G_{\lambda 13}$$

15. The method of any preceding claim, wherein the step of determining a difference in attenuation of the light signal between the first wavelength and the second wavelength utilizes the equation:

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G'_{\lambda 12}$$

and the step of determining a difference in attenuation of the light signal between the first wavelength and the third wavelength utilizes the equation:

$$\Delta A_{\lambda 13} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 3}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 3}\right)[HbO_2]dB + \Delta G'_{\lambda 13}$$

16. The method of claim 5 or 6, comprising determining a concentration of oxyhemoglobin and a concentration of deoxyhemoglobin within the subject's tissue at an initial time t1 and a subsequent time t2, said method further comprising the steps of:

(a) determining a photon pathlength d*B;
(b) determining the concentration of oxyhemoglobin and the concentration of deoxyhemoglobin within the subject's tissue at the initial time t1 using the equation:

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix} (dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix} (dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix}_{t1}$$

where Ψ_{HbO2} represents the first calibration constant, $\dot{\Psi}_{Hb}$ represents the second calibration constant, A_{HbO2} represents a difference in attenuation of light signal attributable to oxyhemoglobin, and A_{Hb} represents a difference in attenuation of light signal attributable to deoxyhemoglobin;
(c) determining a change in the concentration of oxyhemoglobin and a change in the concentration of deoxyhemoglobin from the initial time t1 to a subsequent second time t2 are determined using the equation:

$$\begin{bmatrix} -\log(I_{t2}/I_{t1})_{\lambda 1}/(d*B_{\lambda 1}) \\ -\log(I_{t2}/I_{t1})_{\lambda 2}/(d*B_{\lambda 2}) \\ -\log(I_{t2}/I_{t1})_{\lambda 3}/(d*B_{\lambda 3}) \end{bmatrix} = \begin{bmatrix} \alpha_{Hb\lambda 1} & \alpha_{HbO_2\lambda 1} \\ \alpha_{Hb\lambda 2} & \alpha_{HbO_2\lambda 2} \\ \alpha_{Hb\lambda 3} & \alpha_{HbO_2\lambda 3} \end{bmatrix} * \begin{bmatrix} \Delta Hb \\ \Delta HbO_2 \end{bmatrix}$$

;and

(d) determining the concentration of oxyhemoglobin and the concentration of deoxyhemoglobin within the subject's tissue at the subsequent time t2 using the equations:

$$[Hb]_{t_2} = \Delta Hb(t_2) + [Hb]_{t_1}$$

and

$$[HbO_2]_{t_2} = \Delta HbO_2(t_2) + [HbO_2]_{t_1}.$$

17. The method of any preceding claim, wherein the sensor is calibrated based on a reference sensor, which reference sensor is calibrated by sensing a reference subject and using empirical data developed from the reference subject at or about the same time as the sensing of the subject's tissue with the sensor.

18. The method of claim 17, wherein the empirical data is collected by discretely sampling a venous blood source and an arterial blood source from the reference subject.

19. The method of claim 17, wherein the empirical data is collected by continuously monitoring a venous blood source and an arterial blood source from the reference subject.

20. The method of any preceding claim, wherein the sensor is calibrated by a method comprising the steps of:

transmitting a light signal from a calibrated NIRS sensor into a reference sample at a predetermined first intensity, wherein the transmitted light signal includes a first wavelength, a second wavelength, and a third wavelength;
sensing a second intensity of the light signal with the calibrated NIRS sensor along the first, second, and third wavelengths after the light signal travels through the reference sample;
determining a first attenuation of the light signal for each of the first, second, and third wavelengths using the predetermined first intensity and the second intensity of the light signal sensed with the calibrated NIRS sensor;
transmitting a light signal from the uncalibrated sensor into the reference sample at the predetermined first intensity, wherein the transmitted light signal includes a first wavelength, a second wavelength, and a third wavelength;
sensing a second intensity of the light signal with the uncalibrated sensor along the first, second, and third wavelengths after the light signal travels through the subject;
determining a second attenuation of the light signal for each of the first, second, and third wavelengths using the predetermined first intensity and the second intensity of the first, second, and third wavelengths sensed with the uncalibrated sensor; and
adjusting the uncalibrated sensor so that the second attenuation substantially agrees with the first attenuation.

21. The method of any preceding claim, further comprising the steps of:

sensing the second intensity of the light signal along three or more selectively chosen wavelengths after the light signal travels through the subject using the sensor;
determining an attenuation of the light signal for at least "n" number of the selectively chosen wavelengths using the predetermined first intensity and the sensed second intensity of the selectively chosen wavelengths, where "n" is an integer equal to or greater than three;
determining a difference in attenuation of the light signal between a first wavelength and each of "n" number

of the selectively chosen wavelengths;
determining the blood oxygen saturation level within the subject's tissue using the difference in attenuation between the first wavelength and each of the "n" number of other selectively chosen wavelengths.

22. The method of claim 21, further comprising:

determining a first calibration constant and a second calibration constant using empirical data developed from the subject at or about the same time as when the sensing occurs; and
determining the blood oxygen saturation level within the subject's tissue using the difference in attenuation between the first wavelength and each of "n" number of the selectively chosen wavelengths, and the first calibration constant and the second calibration constant.

Patentansprüche

1. Verfahren zum nichtinvasiven Bestimmen eines gesamten Blutsauerstoffsättigungsniveaus innerhalb des Gewebes einer Person unter Verwendung eines Nah-Infrarotsensors, wobei der Sensor einen Wandlerabschnitt (10) und einen Prozessorabschnitt (12) besitzt, wobei das Verfahren die Schritte umfasst:

Senden eines Lichtsignals mit einer vorgegebenen ersten Stärke unter Verwendung des Sensors in das Gewebe der Person, wobei das gesendete Lichtsignal eine erste Wellenlänge, eine zweite Wellenlänge und eine dritte Wellenlänge enthält; und
Erfassen einer zweiten Stärke des Lichtsignals unter Verwendung des Sensors bei der ersten, zweiten und dritten Wellenlänge, nachdem das Lichtsignal durch die Person hindurchgegangen ist; **dadurch gekennzeichnet, dass**:

der Sensor unter Verwendung von empirischen Daten, die zur selben Zeit oder ungefähr zur selben Zeit wie die Erfassung des Gewebes mit dem Sensor gesammelt werden, kalibriert wird, um die Lichtsignaldämpfung, die aus dem Streuen des Lichtsignals innerhalb des Gewebes der Person resultiert, und eine oder beide Lichtsignaldämpfungen aufgrund von festen Gewebeabsorbern und Sensorschwankungen zu berücksichtigen; und durch:

Bestimmen einer Dämpfung des Lichtsignals für jede der ersten, zweiten und dritten Wellenlänge unter Verwendung der vorgegebenen ersten Stärke und der erfassten zweiten Stärke der ersten, zweiten und dritten Wellenlänge;
Bestimmen eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der zweiten Wellenlänge und zwischen der ersten Wellenlänge und der dritten Wellenlänge; und
Bestimmen des Blutsauerstoffsättigungsniveaus innerhalb des Gewebes der Person unter Verwendung des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und der zweiten Wellenlänge und des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und der dritten Wellenlänge.

2. Verfahren nach Anspruch 1, wobei der Sensor unter Verwendung der Gleichung

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2$$

kalibriert wird.

3. Verfahren nach Anspruch 2, das ferner die Schritte umfasst:

Bestimmen eines Blutsauerstoffsättigungsniveaus, das einem arteriellen Blut innerhalb des Gewebes der Person zuschreibbar ist, unter Verwendung einer Pulsoxymetrietechnik; und
Bestimmen eines Blutsauerstoffsättigungsniveaus, das einem venösen Blut innerhalb des Gewebes der Person zuschreibbar ist, unter Verwendung der Gleichung:

$$SvO_2 = \frac{CrSO_2 - (Ka * SpO_2)}{Kv}.$$

4. Verfahren nach Anspruch 2, wobei der Sensor unter Verwendung von empirischen Daten kalibriert ist, um eine erste Kalibrierungskonstante und eine zweite Kalibrierungskonstante zu bestimmen.

5. Verfahren nach Anspruch 1, das ferner die Schritte umfasst:

Bestimmen einer ersten Kalibrierungskonstante und einer zweiten Kalibrierungskonstante unter Verwendung von empirischen Daten, die aus der Person zur selben Zeit oder ungefähr zur selben Zeit wie, wenn die Erfassung stattfindet, entstanden sind; und
Bestimmen des Blutsauerstoffsättigungsniveaus innerhalb des Gewebes der Person unter Verwendung des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und der zweiten Wellenlänge und des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und der dritten Wellenlänge und der ersten Kalibrierungskonstante und der zweiten Kalibrierungskonstante.

6. Verfahren nach Anspruch 1, das ferner die Schritte umfasst:

Bestimmen einer ersten Kalibrierungskonstante und einer zweiten Kalibrierungskonstante unter Verwendung von empirischen Daten, die aus der Person zur selben Zeit oder ungefähr zur selben Zeit, zu der die Erfassung stattfindet, entstanden sind; und
Kalibrieren des Sensors unter Verwendung der ersten Kalibrierungskonstante und der zweiten Kalibrierungskonstante.

7. Verfahren nach Anspruch 5 oder 6, wobei die empirischen Daten gesammelt werden, indem eine Probe von einer venösen Blutquelle und einer arteriellen Blutquelle von der Person getrennt genommen werden.

8. Verfahren nach Anspruch 5 oder 6, wobei die empirischen Daten gesammelt werden, indem eine venöse Blutquelle und eine arterielle Blutquelle von der Person fortlaufend überwacht wird.

9. Verfahren nach Anspruch 5 oder 6, wobei der Sensor unter Verwendung der Gleichung

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2$$

kalibriert wird.

10. Verfahren nach einem der Ansprüche 4-9, wobei der Schritt des Bestimmens des Blutsauerstoffsättigungsniveaus innerhalb des Gewebes der Person die Gleichung

$$CrSO_2\% = \frac{(A_{HbO_2} - \Psi_{HbO_2})}{(A_{HbO_2} - \Psi_{HbO_2} + A_{Hb} - \Psi_{Hb})} * 100\%$$

verwendet, wobei Ψ_{HbO2} die erste Kalibrierungskonstante repräsentiert, Ψ_{Hb} die zweite Kalibrierungskonstante repräsentiert, A_{HbO2} einen Unterschied in der Dämpfung des Lichtsignals, die dem Oxyhämoglobin zuschreibbar ist, repräsentiert und A_{Hb} einen Unterschied in der Dämpfung des Lichtsignals, die dem Desoxyhämoglobin zuschreibbar ist, repräsentiert.

11. Verfahren nach Anspruch 10, das ferner die Schritte umfasst:

Bestimmen einer Photonenweglänge d*B; und
Bestimmen der Konzentration des Oxyhämoglobins und des Desoxyhämoglobins innerhalb des Gewebes der

Person unter Verwendung der ersten und der zweiten Kalibrierungskonstante.

12. Verfahren nach Anspruch 11, wobei die Konzentration des Oxyhämoglobins und des Deoxyhämoglonins innerhalb des Gewebes der Person unter Verwendung der Gleichung

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix}(dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix}(dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix}$$

bestimmt wird.

13. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Schritt des Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der zweiten Wellenlänge die Gleichung

$$\Delta A_{\lambda 12} = \log\left[\left(\frac{I_{\lambda 1}}{Io_{\lambda 1}}\right) * \left(\frac{I_{\lambda 2}}{Io_{\lambda 2}}\right)\right] = \Delta\alpha_{c\lambda 12} c dB + \Delta G_{\lambda 12}$$

verwendet und der Schritt des Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der dritten Wellenlänge die Gleichung

$$\Delta A_{\lambda 13} = \log\left[\left(\frac{I_{\lambda 1}}{Io_{\lambda 1}}\right) * \left(\frac{I_{\lambda 3}}{Io_{\lambda 3}}\right)\right] = \Delta\alpha_{c\lambda 13} c dB + \Delta G_{\lambda 13}$$

verwendet.

14. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Schritt der Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der zweiten Wellenlänge die Gleichung

$$\Delta A_{\lambda 12} = (\alpha_{Hb\lambda 1} - \alpha_{Hb\lambda 2})[Hb] dB + (\alpha_{HbO_2\lambda 1} - \alpha_{HbO_2\lambda 2})[HbO_2] dB + \Delta G_{\lambda 12}$$

verwendet und der Schritt des Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der dritten Wellenlänge die Gleichung

$$\Delta A_{\lambda 13} = (\alpha_{Hb\lambda 1} - \alpha_{Hb\lambda 3})[Hb] dB + (\alpha_{HbO_2\lambda 1} - \alpha_{HbO_2\lambda 3})[HbO_2] dB + \Delta G_{\lambda 13}$$

verwendet.

15. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Schritt des Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der zweiten Wellenlänge die Gleichung

$$\Delta A_{\lambda 12} = (\alpha_{Hb\lambda 1} - \alpha_{Hb\lambda 2})[Hb] dB + (\alpha_{HbO_2\lambda 1} - \alpha_{HbO_2\lambda 2})[HbO_2] dB + \Delta G_{\lambda 12}$$

verwendet und der Schritt des Bestimmens eines Unterschieds in der Dämpfung des Lichtsignals zwischen der ersten Wellenlänge und der dritten Wellenlänge die Gleichung

$$\Delta A_{\lambda 13} = (\alpha_{Hb\lambda 1} - \alpha_{Hb\lambda 3})[Hb]dB + (\alpha_{HbO_2\lambda 1} - \alpha_{HbO_2\lambda 3})[HbO_2]dB + \Delta G_{\lambda 13}$$

verwendet.

16. Verfahren nach Anspruch 5 oder 6, das das Bestimmen einer Konzentration des Oxyhämoglobins und einer Konzentration des Desoxyhämoglobins innerhalb des Gewebes der Person zu einer Anfangszeit t1 und einer späteren zeit t2 umfasst, wobei das Verfahren ferner die Schritte umfasst:

(a) Bestimmen einer Photonenweglänge d*B;
(b) Bestimmen der Konzentration des Oxyhämoglobins und der Konzentration des Desoxyhämoglobins innerhalb des Gewebes der Person zu der Anfangszeit t1 unter Verwendung der Gleichung:

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix}(dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix}(dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix},$$

wobei T_{HbO2} die erste Kalibrierungskonstante repräsentiert, Ψ_{Hb} die zweite Kalibrierungskonstante repräsentiert, A_{HbO2} einen Unterschied in der Dämpfung des Lichtsignals, die dem Oxyhämoglobin zuschreibbar ist, repräsentiert und A_{Hb} einen Unterschied in der Dämpfung des Lichtsignals, die dem Desoxyhämoglobin zuschreibbar ist, repräsentiert;
(c) Bestimmen einer Änderung in der Konzentration des Oxyhämoglobins und einer Änderung in der Konzentration des Desoxyhämoglobins von der Anfangszeit t1 zu einer späteren zweiten Zeit t2 bestimmt werden unter Verwendung der Gleichung:

$$\begin{bmatrix} -\frac{\log[(I]_{t2} - I_{t1})_{\lambda 1}}{d * B_{\lambda 1}} \\ -\frac{\log[(I]_{t2} - I_{t1})_{\lambda 2}}{d * B_{\lambda 2}} \\ -\frac{\log[(I]_{t2} - I_{t1})_{\lambda 3}}{d * B_{\lambda 3}} \end{bmatrix} = \begin{bmatrix} \alpha_{Hb\lambda 1} & \alpha_{HbO_2\lambda 1} \\ \alpha_{Hb\lambda 1} & \alpha_{HbO_2\lambda 2} \\ \alpha_{Hb\lambda 3} & \alpha_{HbO_2\lambda 3} \end{bmatrix} * \begin{bmatrix} \Delta Hb \\ \Delta HbO_2 \end{bmatrix};$$

und
(d) Bestimmen der Konzentration des Oxyhämoglobins und der Konzentration des Desoxyhämoglobins innerhalb des Gewebes der Person zu der späteren Zeit t2 unter Verwendung der Gleichungen:

$$[Hb]_{t_2} = \Delta Hb(t_2) + [Hb]_{t_1}$$

und

$$[HbO_2]_{t_2} = \Delta HbO_2(t_2) + [HbO_2]_{t_1}.$$

17. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Sensor aufgrund eines Referenzsensors kalibriert wird, der seinerseits kalibriert wird, indem eine Referenzperson erfasst wird und unter Verwendung von empirischen Daten, die aus der Referenzperson zur selben Zeit oder ungefähr zur selben Zeit wie die Erfassung des Gewebes der Person mit dem Sensor entstanden sind.

18. Verfahren nach Anspruch 17, wobei die empirischen Daten gesammelt werden, indem eine Probe einer venösen Blutquelle und einer arteriellen Blutquelle der Referenzperson getrennt genommen werden.

19. Verfahren nach Anspruch 17, wobei die empirischen Daten gesammelt werden, indem eine venöse Blutquelle und eine arterielle Blutquelle von der Referenzperson fortlaufend überwacht werden.

20. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Sensor durch ein Verfahren kalibriert wird, das die Schritte umfasst:

Senden eines Lichtsignals mit einer vorgegebenen ersten Stärke von einem kalibrierten NIRS-Sensor in eine Referenzprobe, wobei das gesendete Lichtsignal eine erste Wellenlänge, eine zweite Wellenlänge und eine dritte Wellenlänge enthält;
Erfassen einer zweiten Stärke des Lichtsignals mit dem kalibrierten NIRS-Sensor bei der ersten, zweiten und dritten Wellenlänge, nachdem das Lichtsignal durch die Referenzprobe hindurchgegangen ist;
Bestimmen einer ersten Dämpfung des Lichtsignals für jede der ersten, zweiten und dritten Wellenlänge unter Verwendung der vorgegebenen ersten Stärke und der zweiten Stärke des mit dem kalibrierten NIRS-Sensor erfassten Lichtsignals;
Senden eines Lichtsignals mit der vorgegebenen ersten Stärke von dem nicht kalibrierten Sensor in die Referenzprobe, wobei das gesendete Lichtsignal eine erste Wellenlänge, eine zweite Wellenlänge und eine dritte Wellenlänge enthält;
Erfassen einer zweiten Stärke des Lichtsignals mit dem nicht kalibrierten Sensor entlang der ersten, zweiten und dritten Wellenlänge, nachdem das Lichtsignal durch die Person hindurchgegangen ist;
Bestimmen einer zweiten Dämpfung des Lichtsignals für jede der ersten, zweiten und dritten Wellenlänge unter Verwendung der vorgegebenen ersten Stärke und der mit dem nicht kalibrierten Sensor erfassten zweiten Stärke der ersten, zweiten und dritten Wellenlänge; und
Einstellen des nicht kalibrierten Sensors, so dass die zweite Dämpfung im Wesentlichen mit der ersten Dämpfung übereinstimmt.

21. Verfahren nach einem der vorhergehenden Ansprüche, das ferner die Schritte umfasst:

Erfassen der zweiten Stärke des Lichtsignals bei drei oder mehr wahlweise gewählten Wellenlängen, nachdem das Lichtsignal durch die Person hindurchgegangen ist, unter Verwendung des Sensors;
Bestimmen einer Dämpfung des Lichtsignals für mindestens eine Anzahl "n" der wahlweise gewählten Wellenlängen unter Verwendung der ersten Stärke und der erfassten zweiten Stärke der wahlweise gewählten Wellenlängen, wobei "n" eine ganze Zahl ist, die gleich oder größer als drei ist;
Bestimmen eines Unterschieds in der Dämpfung des Lichtsignals zwischen einer ersten Wellenlänge und jeder der Anzahl "n" wahlweise gewählten Wellenlängen;
Bestimmen des Blutsauerstoffsättigungsniveaus innerhalb des Gewebes der Person unter Verwendung des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und jeder der Anzahl "n" der anderen wahlweise gewählten Wellenlängen.

22. Verfahren nach Anspruch 21, das ferner umfasst:

Bestimmen einer ersten Kalibrierungskonstanten und einer zweiten Kalibrierungskonstanten unter Verwendung von empirischen Daten, die aus der Person zur selben Zeit oder ungefähr zur selben zeit, zu der die Erfassung stattfindet, entstanden sind; und
Bestimmen des Blutsauerstoffsättigungsniveaus innerhalb des Gewebes der Person unter Verwendung des Unterschieds in der Dämpfung zwischen der ersten Wellenlänge und jeder der Anzahl "n" der wahlweise gewählten Wellenlängen und der ersten Kalibrierungskonstanten und der zweiten Kalibrierungskonstanten.

Revendications

1. Procédé pour déterminer de manière non invasive un niveau total de saturation du sang en oxygène à l'intérieur d'un tissu d'un sujet en utilisant un capteur spectrophotométrique dans l'infrarouge proche, le capteur ayant une partie de transducteur (10) et une partie de processeur (12), ledit procédé comportant les étapes consistant à :

transmettre un signal lumineux dans le tissu du sujet à une première intensité prédéterminée en utilisant le

capteur, le signal lumineux transmis incluant une première longueur d'onde, une deuxième longueur d'onde et une troisième longueur d'onde ; et
détecter une seconde intensité du signal lumineux, en utilisant le capteur, ainsi que les première, deuxième et troisième longueurs d'onde après que le signal lumineux se soit propagé à travers le sujet ; **caractérisé en ce que** :

le capteur est étalonné en utilisant des données empiriques collectées en même temps ou pratiquement en même temps que la détection du tissu avec le capteur pour rendre compte de l'atténuation du signal lumineux résultant de la diffusion du signal lumineux à l'intérieur du tissu du sujet et d'un ou deux éléments parmi l'atténuation du signal lumineux due à des absorbeurs de tissu fixes et la variabilité du capteur ; et :

en déterminant une atténuation du signal lumineux pour chacune des première, deuxième et troisième longueurs d'onde en utilisant la première intensité prédéterminée et la seconde intensité détectée des première, deuxième et troisième longueurs d'onde ;
en déterminant une différence d'atténuation du signal lumineux entre la première longueur d'onde et la deuxième longueur d'onde, et entre la première longueur d'onde et la troisième longueur d'onde ; et en déterminant le niveau de saturation du sang en oxygène dans le tissu du sujet en utilisant la différence d'atténuation entre la première longueur d'onde et la deuxième longueur d'onde, et la différence d'atténuation entre la première longueur d'onde et la troisième longueur d'onde.

2. Procédé selon la revendication 1, dans lequel le capteur est étalonné en utilisant l'équation :

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2.$$

3. Procédé selon la revendication 2, comportant en outre les étapes consistant à :

déterminer un niveau de saturation du sang en oxygène imputable au sang artériel à l'intérieur du tissu du sujet en utilisant une technique d'oxymétrie de pouls ; et
déterminer un niveau de saturation du sang en oxygène imputable au sang veineux dans le tissu du sujet en utilisant l'équation :

$$SvO_2 = \frac{CrSO_2 - (Ka * SpO_2)}{Kv}$$

4. Procédé selon la revendication 2, dans lequel le capteur est étalonné en utilisant des données empiriques pour déterminer une première constante d'étalonnage et une seconde constante d'étalonnage.

5. Procédé selon la revendication 1, comportant en outre les étapes consistant à :

déterminer une première constante d'étalonnage et une seconde constante d'étalonnage en utilisant des données empiriques développées à partir du sujet en même temps ou pratiquement en même temps que lorsque la détection a lieu ; et
déterminer le niveau de saturation du sang en oxygène à l'intérieur du tissu du sujet en utilisant la différence d'atténuation entre la première longueur d'onde et la deuxième longueur d'onde, et la différence d'atténuation entre la première longueur d'onde et la troisième longueur d'onde, et la première constante d'étalonnage et la seconde constante d'étalonnage.

6. Procédé selon la revendication 1, comportant en outre les étapes consistant à :

déterminer une première constante d'étalonnage et une seconde constante d'étalonnage en utilisant des données empiriques développées à partir du sujet en même temps ou pratiquement en même temps que lorsque la détection a lieu ; et
étalonner le capteur en utilisant la première constante d'étalonnage et la seconde constante d'étalonnage.

7. Procédé selon la revendication 5 ou 6, dans lequel les données empiriques sont collectées en échantillonnant discrètement une source de sang veineux et une source de sang artériel provenant du sujet.

8. Procédé selon la revendication 5 ou 6, dans lequel les données empiriques sont collectées en surveillant de manière continue une source de sang veineux et une source de sang artériel provenant du sujet.

9. Procédé selon la revendication 5 ou 6, dans lequel le capteur est étalonné en utilisant l'équation :

$$SmvO_2 = Kv*SvO_2 + Ka*SaO_2.$$

10. Procédé selon l'une quelconque des revendications 4 à 9, dans lequel l'étape de détermination du niveau de saturation du sang en oxygène à l'intérieur du tissu du sujet utilise l'équation :

$$CrSO_2\% = \frac{\left(A_{HbO_2} - \Psi_{HbO_2}\right)}{\left(A_{HbO_2} - \Psi_{HbO_2} + A_{Hb} - \Psi_{Hb}\right)} * 100\%$$

où ψ_{HbO2} représente la première constante d'étalonnage, ψ_{Hb} représente la seconde constante d'étalonnage, A_{HbO2} représente une différence d'atténuation du signal lumineux imputable à l'oxyhémoglobine ; et A_{Hb} représente une différence d'atténuation du signal lumineux imputable à la déoxyhémoglobine.

11. Procédé selon la revendication 10, comportant en outre les étapes consistant à :

déterminer une longueur de trajet de photons d*B ; et
déterminer la concentration d'oxyhémoglobine et de déoxyhémoglobine à l'intérieur du tissu du sujet en utilisant les première et seconde constantes d'étalonnage.

12. Procédé selon la revendication 11, dans lequel la concentration d'oxyhémoglobine et de déoxyhémoglobine à l'intérieur du tissu du sujet est déterminée en utilisant l'équation :

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix} (dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix} (dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix}.$$

13. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la deuxième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 12} = \log\left[\left(I_{\lambda 1} / Io_{\lambda 1}\right) * \left(I_{\lambda 2} / Io_{\lambda 2}\right)\right] = \Delta\alpha_{c\lambda 12} cdB + \Delta G_{\lambda 12}$$

et l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la troisième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 13} = \log\left[\left(I_{\lambda 1} / Io_{\lambda 1}\right) * \left(I_{\lambda 3} / Io_{\lambda 3}\right)\right] = \Delta\alpha_{c\lambda 13} cdB + \Delta G_{\lambda 13}.$$

14. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la deuxième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G_{\lambda 12}$$

et l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la troisième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 13} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 3}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 3}\right)[HbO_2]dB + \Delta G_{\lambda 13}$$

15. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la deuxième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 12} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 2}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 2}\right)[HbO_2]dB + \Delta G'_{\lambda 12}$$

et l'étape de détermination d'une différence d'atténuation du signal lumineux entre la première longueur d'onde et la troisième longueur d'onde utilise l'équation :

$$\Delta A_{\lambda 13} = \left(\alpha'_{Hb\lambda 1} - \alpha'_{Hb\lambda 3}\right)[Hb]dB + \left(\alpha'_{HbO_2\lambda 1} - \alpha'_{HbO_2\lambda 3}\right)[HbO_2]dB + \Delta G'_{\lambda 13}$$

16. Procédé selon la revendication 5 ou 6, comportant la détermination d'une concentration d'oxyhémoglobine et d'une concentration de déoxyhémoglobine à l'intérieur du tissu du sujet à un instant initial t1 et à un instant ultérieur t2, ledit procédé comportant en outre les étapes consistant à :

(a) déterminer une longueur de trajet de photons d*B ;
(b) déterminer la concentration d'oxyhémoglobine et la concentration de déoxyhémoglobine à l'intérieur du tissu du sujet à l'instant initial t1 en utilisant l'équation :

$$\begin{bmatrix} A_{Hb} \\ A_{HbO_2} \end{bmatrix}(dB)^{-1} - \begin{bmatrix} \Psi_{Hb} \\ \Psi_{HbO_2} \end{bmatrix}(dB)^{-1} = \begin{bmatrix} Hb \\ HbO_2 \end{bmatrix}_{t1}$$

où ψ_{HbO2} représente la première constante d'étalonnage, ψ_{Hb} représente la seconde constante d'étalonnage, A_{HbO2} représente une différence d'atténuation du signal lumineux imputable à l'oxyhémoglobine ; et A_{Hb} représente une différence d'atténuation du signal lumineux imputable à la déoxyhémoglobine ;
(c) déterminer un changement dans la concentration d'oxyhémoglobine et un changement dans la concentration de déoxyhémoglobine de l'instant initial t1 à un second instant ultérieur t2 qui sont déterminés en utilisant l'équation :

$$\begin{bmatrix} -\log(I_{t2}/I_{t1})_{\lambda 1}/(d*B_{\lambda 1}) \\ -\log(I_{t2}/I_{t1})_{\lambda 2}/(d*B_{\lambda 2}) \\ -\log(I_{t2}/I_{t1})_{\lambda 3}/(d*B_{\lambda 3}) \end{bmatrix} = \begin{bmatrix} \alpha_{Hb\lambda 1} & \alpha_{HbO_2\lambda 1} \\ \alpha_{Hb\lambda 2} & \alpha_{HbO_2\lambda 2} \\ \alpha_{Hb\lambda 3} & \alpha_{HbO_2\lambda 3} \end{bmatrix} * \begin{bmatrix} \Delta Hb \\ \Delta HbO_2 \end{bmatrix}$$

et
(d) déterminer la concentration d'oxyhémoglobine et la concentration de déoxyhémoglobine à l'intérieur du tissu

du sujet à l'instant ultérieur t2 en utilisant les équations ;

$$[Hb]_{t_2} = \Delta Hb(t_2) + [Hb]_{t_1}$$

et

$$[HbO_2]_{t_2} = \Delta HbO_2(t_2) + [HbO_2]_{t_1}.$$

17. Procédé selon l'une quelconque des revendications précédentes, dans lequel le capteur est étalonné sur la base d'un capteur de référence, lequel capteur de référence est étalonné en détectant un sujet de référence et en utilisant des données empiriques développées à partir du sujet de référence en même temps ou pratiquement en même temps que la détection du tissu du sujet avec le capteur.

18. Procédé selon la revendication 17, dans lequel les données empiriques sont collectées en échantillonnant discrètement une source de sang veineux et une source de sang artériel provenant du sujet de référence.

19. Procédé selon la revendication 17, dans lequel les données empiriques sont collectées en surveillant de manière continue une source de sang veineux et une source de sang artériel provenant du sujet de référence.

20. Procédé selon l'une quelconque des revendications précédentes, dans lequel le capteur est étalonné par un procédé comportant les étapes consistant à :

transmettre un signal lumineux provenant d'un capteur NIRS étalonné dans un échantillon de référence à une première intensité prédéterminée, le signal lumineux transmis incluant une première longueur d'onde, une deuxième longueur d'onde et une troisième longueur d'onde ;
détecter une seconde intensité du signal lumineux avec le capteur NIRS étalonné ainsi que les première, deuxième et troisième longueurs d'onde après que le signal lumineux se soit propagé à travers l'échantillon de référence ;
déterminer une première atténuation du signal lumineux pour chacune des première, deuxième et troisième longueurs d'ondes en utilisant la première intensité prédéterminée et la seconde intensité du signal lumineux détectée avec le capteur NIRS étalonné ;
transmettre un signal lumineux provenant du capteur non étalonné dans l'échantillon de référence à la première intensité prédéterminée, le signal lumineux transmis incluant une première longueur d'onde, une deuxième longueur d'onde et une troisième longueur d'onde ;
détecter une seconde intensité du signal lumineux avec le capteur non étalonné ainsi que les première, deuxième et troisième longueurs d'onde après que le signal lumineux se soit propagé à travers le sujet ;
déterminer une seconde atténuation du signal lumineux pour chacune des première, deuxième et troisième longueurs d'onde en utilisant la première intensité prédéterminée et la seconde intensité des première, deuxième et troisième longueurs d'onde détectées avec le capteur non étalonné ; et
régler le capteur non étalonné de sorte que la seconde atténuation corresponde sensiblement à la première atténuation.

21. Procédé selon l'une quelconque des revendications précédentes, comportant en outre les étapes consistant à :

détecter la seconde intensité du signal lumineux ainsi que trois ou plus de trois longueurs d'onde choisies sélectivement après que le signal lumineux se soit propagé à travers le sujet en utilisant le capteur ;
déterminer une atténuation du signal lumineux pour au moins "n" nombre de longueurs d'onde sélectivement choisies en utilisant la première intensité prédéterminée et la seconde intensité détectée des longueurs d'onde choisies sélectivement, où "n" est un entier égal ou supérieur à trois ;
déterminer une différence d'atténuation du signal lumineux entre une première longueur d'onde et chaque longueur d'onde parmi "n" nombre des longueurs d'onde choisies sélectivement ;
déterminer le niveau de saturation du sang en oxygène à l'intérieur du tissu du sujet en utilisant la différence d'atténuation entre la première longueur d'onde et chaque longueur d'onde parmi le nombre "n" d'autres longueurs d'onde choisies sélectivement.

22. Procédé selon la revendication 21, comportant en outre les étapes consistant à :

déterminer une première constante d'étalonnage et une seconde constante d'étalonnage en utilisant des données empiriques développées à partir du sujet en même temps ou pratiquement en même temps que lorsque la détection a lieu ; et
déterminer le niveau de saturation du sang en oxygène à l'intérieur du tissu du sujet en utilisant la différence d'atténuation entre la première longueur d'onde et chaque longueur d'onde parmi le nombre "n" des longueurs d'onde choisies sélectivement, et la première constante d'étalonnage et la seconde constante d'étalonnage.

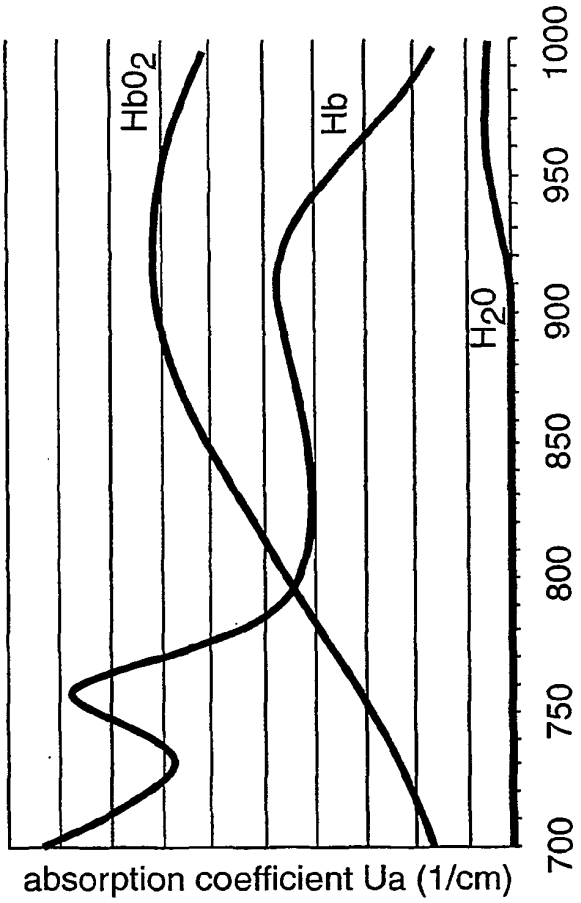

FIG. 5

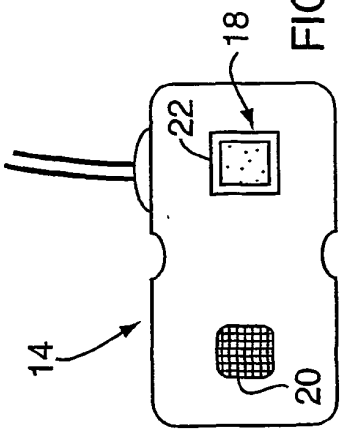

FIG. 3

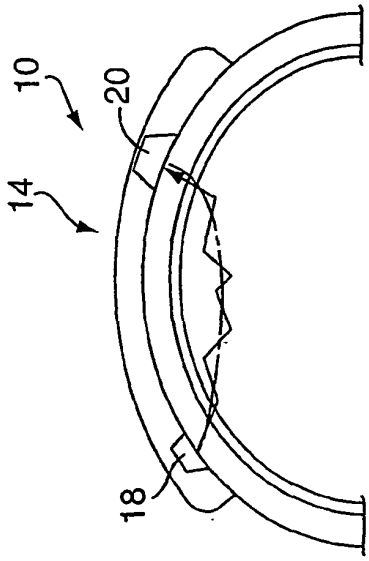

FIG. 1

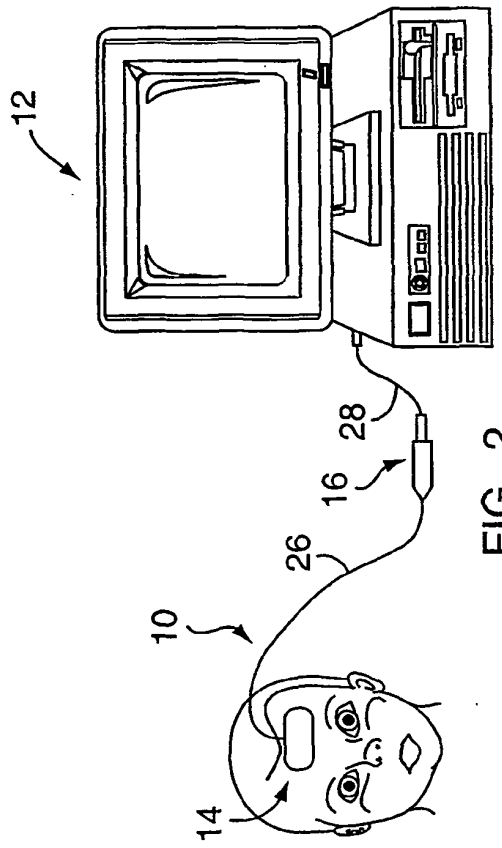

FIG. 2

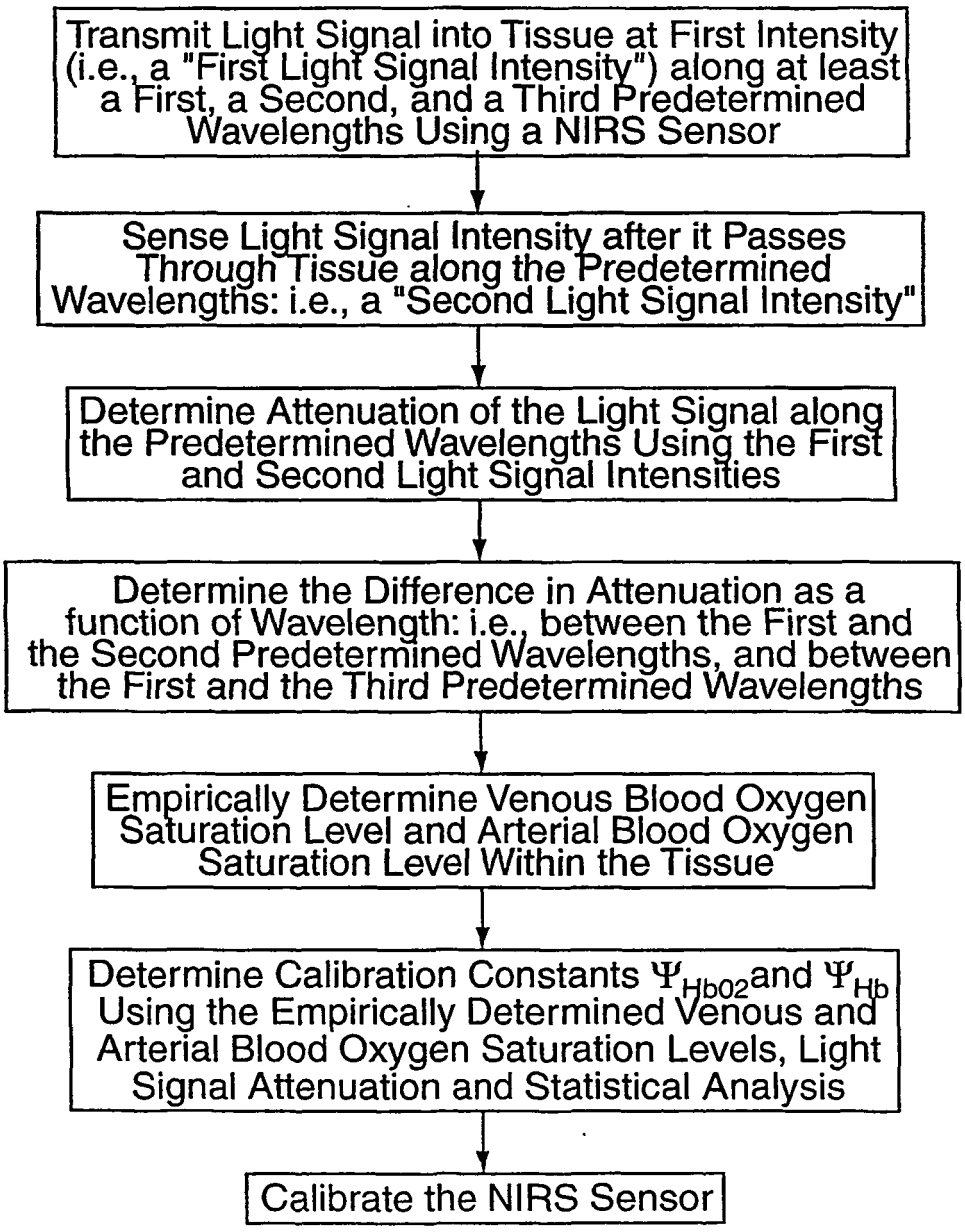
Transmit Light Signal into Tissue at First Intensity (i.e., a "First Light Signal Intensity") along at least a First, a Second, and a Third Predetermined Wavelengths Using a NIRS Sensor
Sense Light Signal Intensity after it Passes Through Tissue along the Predetermined Wavelengths: i.e., a "Second Light Signal Intensity"
Determine Attenuation of the Light Signal along the Predetermined Wavelengths Using the First and Second Light Signal Intensities
Determine the Difference in Attenuation as a function of Wavelength: i.e., between the First and the Second Predetermined Wavelengths, and between the First and the Third Predetermined Wavelengths
Empirically Determine Venous Blood Oxygen Saturation Level and Arterial Blood Oxygen Saturation Level Within the Tissue
Determine Calibration Constants Ψ_{Hb02} and Ψ_{Hb} Using the Empirically Determined Venous and Arterial Blood Oxygen Saturation Levels, Light Signal Attenuation and Statistical Analysis
Calibrate the NIRS Sensor

FIG. 4

REFERENCES CITED IN THE DESCRIPTION

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- **BENNI P B et al.** A novel near-infrared spectroscopy (NIRS) system for measuring regional oxygen saturation. *PROCEEDINGS IEEE 21st ANNUAL NE BIO-ENGINEERING CONFERENCE,* 1995, 105-107 **[0017]**

专利名称(译)	无创分光光度法血氧监测方法		
公开(公告)号	EP1259791B1	公开(公告)日	2013-11-13
申请号	EP2001932756	申请日	2001-04-30
申请(专利权)人(译)	CAS医疗系统，INC.		
当前申请(专利权)人(译)	CAS医疗系统，INC.		
[标]发明人	BENNI PAUL		
发明人	BENNI, PAUL		
IPC分类号	A61B5/00 G01N21/35 G01N21/49 A61B5/145 A61B5/1455 A61B5/1495 G01N21/27 G01N33/49		
CPC分类号	G01N21/359 A61B5/14553 A61B5/1495 G01N21/49		
优先权	60/201359 2000-05-02 US		
其他公开文献	EP1259791A4 EP1259791A2		
外部链接	Espacenet		

摘要(译)

提供了一种用于非侵入性地确定受试者组织内的血氧饱和度水平的方法和装置，其利用近红外分光光度（NIRS）传感器，其能够将光信号传输到受试者的组织中并且一旦感测到光信号就感测到该信号。通过透射率或反射率穿过组织。该方法包括将光信号的衰减确定为以下之和的步骤：（i）归因于脱氧血红蛋白的衰减；（ii）由氧合血红蛋白引起的衰减；（iii）可归因于受试者组织内光散射的衰减。本方法还使得可以解释归因于固定或恒定的光吸收生物组织成分的衰减，以及可归因于传感器的可变特性的衰减。通过确定作为波长的函数的差分衰减，可归因于组织光散射特性，固定光吸收分量和测量设备特性的衰减在数学上相对于由脱氧血红蛋白引起的衰减和由氧合血红蛋白引起的衰减在数学上被抵消或最小化。

$$O_2\ saturation\% = \frac{HbO_2}{(HbO_2 + Hb)} \times 100\% \quad (Eqn.1)$$