논문 93-10

Optical Measurement of Blood Oxygen Saturation for Artificial Heart Using Wavelength of 665nm and 805nm

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665nm와 805nm의 파장을 이용한 인공심장용 혈중 산소포화도의 광학적 측정

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Abstract

This study describes a non-invasive optical sensor and system in order to obtain oxygen saturation of blood, *in-vitro*. The sensor contains LED 665nm and 805nm of wavelength for light source and PIN photodiode for light detector in flat pack. The sensor system for measurement of oxygen saturation has breadboarded, including signal amplifier, filter, displayer, A/D converter, microprocessor and memory. Experimental set-up for non-invasive measurement of oxygen saturation *in-vitro* was done.

When the variation of oxygen saturation is compared with that of each wavelength, the variation of 665nm is more than that of 805nm by five times. As oxygen saturation varies from 100% to 60%, and the reflection ratio (R805/R665) is changed linearly. The oxygen saturation in 100%~60% range can be measured with about 5% resolution by the developed sensor, such that if this sensor connects with the main artery and vein, the artificial heart can be controlled rapidly and precisely from measurement of the sensor.

요 약

본 논문에서는 혈액의 산소포화도를 비추출식으로 측정하기 위한 광 센서와 센서 시스템을 나타내었다. 광 센서의 광원으로는 665nm와 805nm의 파장을 가지는 LED를 사용하여 구성하였고, 감지기로는 PIN 포토다이오드를 이용하여 각 센서부를 구성하였다. 이들 광원과 감지기를 이용하여 Flat Pack에 광 센서를 제작하였다. 혈액의 산소포화도를 측정하기 위한 센서 시스템을 신호 증폭기, 필터, 디스 플레이 장치, A/D 컨버터, 마이크로프로세서와 메모리 등으로 설계, 제작하였다. 그리고, 비추출식으로 산소포화도를 측정하기 위한 모의 실험 장치를 구성하여 모의 실험을 행하였다.

실험 결과, 산소포화도의 변화에 따른 각 파장의 출력치 변화를 비교하여 보면 665nm의 파장에서의 출력 변화가 805nm의 파장에서의 출력 변화보다 5배정도 크게 변화하였다. 그리고, 산소포화도가 100%에서 60%로 변화할때, 각 파장의 비(R805/R665)는 선형적으로 변화하였다. 그러므로, 100%에서 60%까지의 산소포화도 범위에서, 개발된 센서는 산소포화도의 변화를 5% 정도의 해상도로서 측정가능하였다. 따라서, 개발된 광센서가 인공 심장의 대동맥과 대정맥에 연결된다면 정확하고 신속하게 인공 심장을 제어할 수 있을 것이다.

Ⅰ. Introduction

The oxygen saturation contained in the blood is measured by gasometric and spectrophotometric method. The gasometric method is simple

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and reliable, but it needs time consuming and cannot be used non-invasively. The spectrophotometric method is equivalent to the gasometric in terms of reliability and accuracy, but it is easier to perform and is able to obtain oxygen saturation non-invasively as varied physiological characteristics. Spectrophotometric method is utilized by reflection and transmission method. Reflection method introduced by Brinkman[1] to overcome the disadvantages of the transmission method : low optical density and non-linearity. The optical reflection method can provide measurement of oxygen saturation in blood by utilizing the relationship between optical absorption differences of oxy- and deoxy-hemoglobin for wavelength.[2] The wavelength of the light is chosen to give a maximum difference between the absorption coefficients of oxy- and deoxy-hemoglobin.

If the oxygen saturation has been measured by gasometric method introvascularly, blood samples must be drawn to analyze oxygen saturation. The oxygen saturation measured by this sampling method changes with various physiological conditions in body. Above method can not provide artificial heart with accurate and rapid information. To control artificial heart precisely, optical sensor measured by reflection method can be attached at the main artery and vein.

The sensor measured by non-invasive oxygen saturation is able to control artificial heart on-time as varied physiological characteristics. This study describes to develop optical sensor that can provide continuous measurement of blood oxygen saturation for artificial heart. Optical sensor system that can analyze oxygen saturation by using microprocessor was developed. Experimental set-up for non-invasive measurement of oxygen saturation *in-vitro* was designed and constituted.

II. Theory of measurement

Basic principles are to vary absorption coefficients of oxy- and deoxy-hemoglobin as the wavelength in the red and near infrared regions. The wavelength of the light is chosen to give a maximum difference between the absorption coefficients of oxy- and deoxy-hemoglobin. Most of the optical sensors in reflection method have been done between 650 and 700nm ; in this region, the absorption coefficient of oxy-hemoglobin is about one ninth of that of deoxy-hemoglobin. Experimental relation of oxygen saturation and the ratio of reflectances at red and near infrared wavelength was derived by Polanyi and Hehir[3] as following equation(1).[4,5,6]

$$\text{Oxygen Saturation} = A + B \times R_{805}/R_{665} \qquad (1)$$

Where A and B are constants that depend on physiological characteristics of the sensor and blood, and R_{805} and R_{665} are the reflectances at the wavelength of 665 and 805nm. Fig. 1 shows that 665nm is the largest absorption coefficient difference between oxy- and deoxy-hemoglobin but 805nm does not affect absorption coefficient, so that this wavelength is able to use the reference value for oxygen saturation.

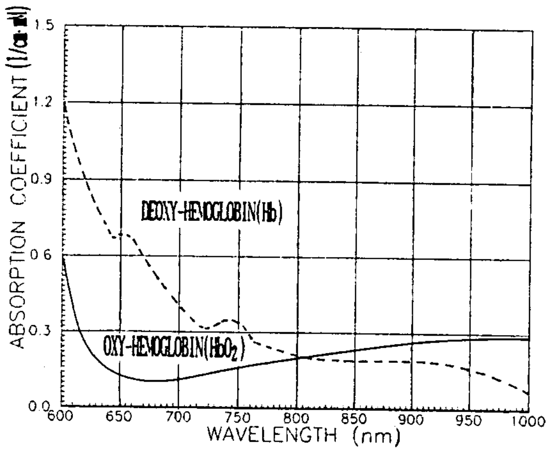

Fig. 1. The relationship between absorption coefficient of hemoglobin and wavelength.

Ⅲ. Optical sensor and sensor system

Fig. 2 shows the photograph of the fabricated optical sensor. Light emitting diodes(LED) for light source and PIN photodiode for light detector were mounted on the top of flat pack. The peak emission wavelengths of LED are 665nm and 805 nm respectively, this LED and PIN photodiode were adhered on flat pack with silver epoxy, and the chips and the external pins were bonded by aluminum wire. The separation distance is about 3mm between the light source and detector. This distance is referred to photon diffusion theory[6,7] that the detected light is diffused light in the deeper layer of the specimen and free of surface scattering.

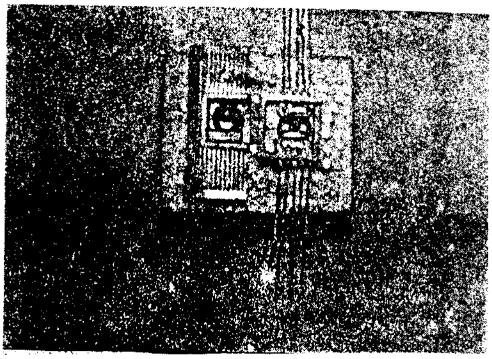

Fig. 2. Optical sensor for measurement of oxygen saturation. (sensor size : left ; 70×90 (mm), right ; 90×100(mm))

Undesired light reflections from the surface of the specimen and direct light effect between the light source and detector were shielded by the isolator. The optical sensor system for measurement of oxygen saturation have breadboarded, including signal amplifier, filter, displayer, A/D converter(8-bit successive approximation A/D converter, ADC0817), microprocessor(Zilog Z80) and memory(ROM 2764, RAM 6116) as shown in Fig. 3. Pulses are generated to drive the light sources. The output of photodiode which correspond to 665nm and 805nm light intensities reflected from specimen is converted to the proportional analog voltage. The S/H(sample and hold) synchronous circuit is triggered by same pulses of LED drive circuit respectively. When the pulse signal enters the P/H(peak and hold) circuit where the reflectance at each wavelength is converted to DC signal, and this DC signal is digitized and analyzed by A/D converter and microprocessor.

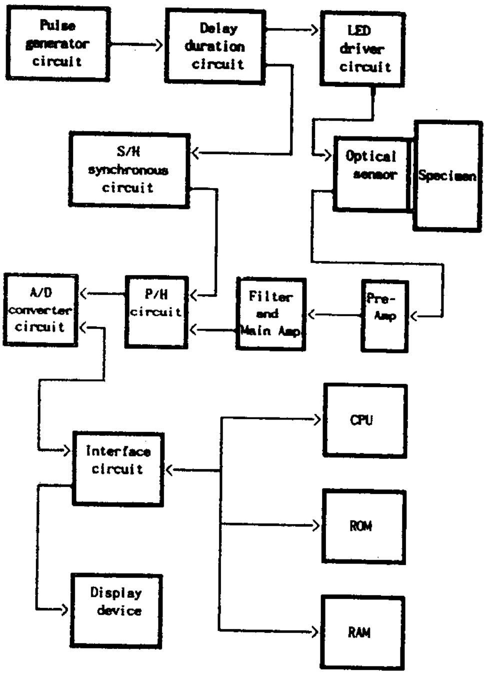

Fig. 3. Block diagram of sensor system for measurement of oxygen saturation.

Ⅳ. Experimental set-up

Experimental set-up for non-invasive measurement of oxygen saturation *in-vitro* was fabricated as shown in Fig. 4. Experimental set-up designed for identical to effects and circumstances as living body by using gas tanks, valves and chamber.[8] The valves 1, 2, and 3 can control volume of O_2, CO_2, and N_2 gases flowing into the gas mixer respectively, and the valve 4 can control quantity of mixed gas flowing into the chamber.

The valve 5 is to draw the blood sample in the chamber easily. The oxygen saturation of the blood sample from the valve 5 is measured by blood gas analyzer, which can be used as reference value to compare with the output of sensor system in Fig. 4. The chamber (diameter 50mm, height 100mm) was manufactured by pyrex glass, and the bottom of the chamber (diameter 15mm, length 5mm) was protruded. Optical sensor adhered at the protrudent side. Undesired light effects were minimized by shielding the outside of chamber.

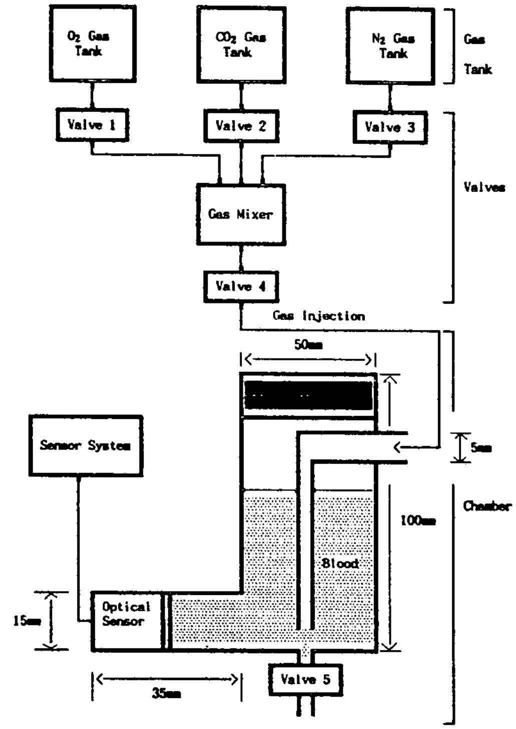

Fig. 4. Block diagram of experimental set-up.

V. Experimental results and discussion

In-vitro experiments were performed by using the optical sensor, sensor system and experimental set-up as described above. The blood of rabbit and cow was treated by heparin to prevent the coagulation of blood. The blood was injected to the chamber, and the gases were blown into the chamber. As the volume of gases was varied, the oxygen saturation of blood in the chamber was changed. The changed oxygen saturation was measured by optical sensor, and sampled to analyze oxygen saturation through the valve 5. Sampled blood was analyzed by blood gas analyzer (COULTER COUNTER, MODEL S-PLUS II) and compared with the ouput of optical sensor. Fig. 5 shows the relationship between variation of oxygen saturation and output of optical sensor.

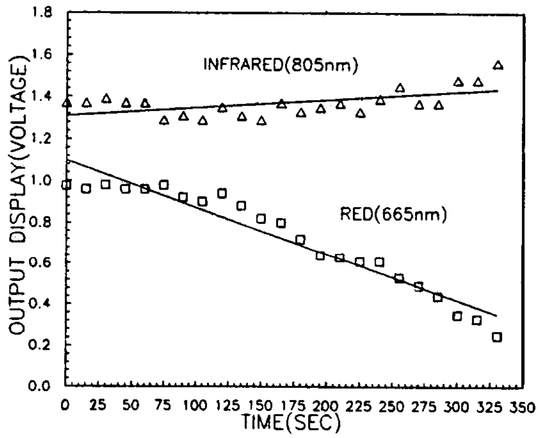

Fig. 5. The relationship between variation of oxygen saturation and output of optical sensor.

As oxygen saturation changes, the optical sensor output was measured with 15 seconds interval. As time passed on, it showed that oxy-hemoglobin was converted into deoxy-hemoglobin. As the result is compared with each wavelength, the output of 665nm wavelength changed sensitively through the variation of oxygen saturation but the output of 805nm wavelength maintained constantly. Fig. 6 shows seven sampled data of the sensor output in Fig. 5. These samples data were analyzed by blood gas analyzer for the reference value of the oxygen saturation. The oxygen saturation of horizontal axis mentioned in Fig. 6 was obtained by blood gas analyzer.

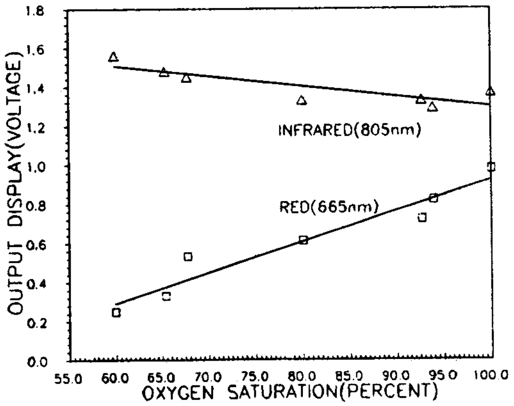

Fig. 6. The relationship between variation of oxygen saturation of each wavelength and output optical sensor.

The relations between variation of oxygen saturation of each wavelength and output of optical sensor were shown in Fig. 7. When variation of oxygen saturation is compared with that of each wavelength, the variation of 665nm is more than that of 805nm by five times. This results agreed with that 665nm is the largest absorption coefficient difference between oxy- and deoxy-hemoglobin and 805nm does not affect absorption coefficient, so that this wavelength is able to use the reference value for oxygen saturation. Fig. 7 shows the relation between oxygen saturation and R805/R665 ratio. As oxygen saturation varies from 100% to 60% and the reflection ratio(R805/R665) is changed linearly. The oxygen saturation can be measured with about 5% resolution in 100%~60% range by the developed sensor, such that if this sensor connects with the main artery and vein, the artificial heart can Fe controlled rapidly and precisely from measurement of the sensor.

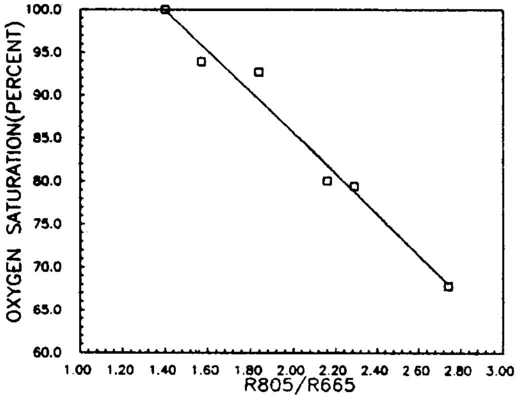

Fig. 7. The relationship between variation of oxygen saturation and ratio of each wavelength.

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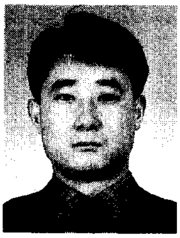

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