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Research on improving the accuracy of near infrared non-invasive hemoglobin detection

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HIGHLIGHTS

- A high performance near-infrared spectrophotometric system.
- Appropriate prepossessing algorithm has been optimized. DOSC & PLS.
- The detection precision almost reaching the requirements of clinical application.

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ABSTRACT

To optimize the accuracy of near-infrared non-invasive hemoglobin (Hb) clinical detection, high-performance instrument and prepossessing algorithm have been investigated. A near-infrared spectrophotometric system was constructed adopting InGaAs detector array with 16 pixels and plane grating spectrometer to obtain high signal noise ratio (SNR) spectral data. In our experiment, we applied the device independently to collect spectra data from 91 volunteers' fingertips non-invasively. Two prediction tests were conducted to verify the effects of preprocessing algorithms improving the accuracy of near-infrared Hb detection and exclude the occasionality of satisfactory results in a single trial. Our non-invasive Hb detection methods were based on partial least squares (PLS). In each test, PLS, MSC coupled with PLS, DOSC coupled with PLS, three methods for non-invasive Hb detection, were analyzed respectively. The results of two trials showed that only DOSC & PLS performed excellently in both predictive ability and stability, obviously better than other two methods. Relative RMSEP was 6.16% in predicting test 1, 6.08% in predicting test 2, almost reaching the requirements of clinical application. It indicates that our independent-developed high-performance instrument and the method DOSC coupled with PLS are promising in non-invasive Hb detection clinical application.

1. Introduction

Hemoglobin (Hb) concentration is one of the most reliable parameter in anemia diagnosing [1,2], as well as an important monitoring index during peri operation period [3].

As a frequent disease, about 1.6 billion people all over the world are suffering from anemia in varying degrees [4]. Every year, more than tens of millions of people died of various diseases caused by anemia. Particularly for neonates, anemia results in more severe impacts. Statistics manifest that more than 30% of neonates suffer from anemia. Anemia will lead to neonates appear symptoms such as anorexia, picky eaters and weakened immunity, which seriously affects the physical and intellectual development of anemic babies. Therefore, early diagnosis is extremely essential in preventing and curing neonatal anemia.

Hb is also utilized as a parameter routinely being monitored during the treatment of patients with vascular, orthopedic and other deep-invasive abdominal surgeries where a great quantity of blood loss possibly occurs. When the loss reaches the minimum margin of oxygen-carrying function, transfusion therapy should be conducted in time. Increasing evidences demonstrate that anemia during peri operation period will induce more postoperative complications, which is a major cause of death especially for patients with multiple diseases [5,6]. Therefore, anesthetists need to acquire actual situation of blood loss by real-time monitoring of Hb levels, so that they are capable of offering effective guidance to blood transfusion intra-operative. It not only can avoid delaying the opportunity of blood transfusion, but also avoid side effects and high costs generated by unnecessary blood transfusions to patients.

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Cyanomethemoglobin (HICN) method is recognized as the standard method for Hb concentration measurement with accurate and stable results. However, disadvantages are unavoidable accompanied with the method. (1) It is an invasive method. Drawing blood increases not only the pain of the patients, but also possibilities for them to acquire diseases infection. Especially for neonates, drawing blood is inconvenient since they possess more narrow blood vessels and a smaller total circulating blood volume than adults. As neonatal immunity is also weak, the risk of diseases infection would be increased by invasive methods. (2) Long detection period. It is difficult for HICN to achieve real-time monitoring since Hb is restricted to be monitored during the process of transfusion. Significant advantage will be attached to measuring Hb in succession especially during surgeries. While in natural disasters or battle grounds, rapid Hb level analysis should be conducted to treat wounded people timely and effectively [7–9]. Therefore, non-invasive Hb concentration measurement technology with the property of fast analysis is in urgent demand, presenting a broad prospect in clinical application.

Near infrared spectroscopy has become one of the focus researches in non-invasive biochemical detection research field ascribed to its non-invasive, fast, multi-component analysis and other advantages [2,10,11]. In 1977, Jobsis first reported Hb absorption characteristics in the near infrared region, which provided theoretical support to near infrared spectroscopy non-invasive Hb detection [12]. In 1995, Kuenstner and Norris put forward "Near infrared hemoglobinometry". Then they measured Hb concentration in vitro based on the hemoglobinometry and got good analysis accuracy [13]. After years of practice and development, non-invasive Hb measurement instruments based on this technology have come out. Radical-7 and Pronto-7 produced by Masimo Corporation could accomplish non-invasive Hb real-time monitoring [14,15]. Though near infrared non-invasive Hb measurement technology has developed tremendously, and numerous researches and practices have been achieved, the not intensely excellent measurement precision and stability are the important obstacles hindering widespread application of this technology in clinic [4].

Now, weak valid spectra signal and strong background interference have become the primary problems which obstacle the development of near infrared non-invasive detection, leading to a difficulty for precision of near infrared non-invasive Hb measurement to meet the requirements of clinical applications. In this paper, to further improve the accuracy of non-invasive detection, high-performance detection system was constructed to obtain spectral data with high signal noise ratio (SNR). Meanwhile, preprocessing algorithms were optimized to filter interference when building non-invasive Hb prediction model. In order to obtain all spectra at the same time and avoid the influence from blood flowing, the 16-pixel InGaAs array detector was adopted. The plane grating was used as a beam-splitting component accordingly. And we also designed 16 independent amplifier circuit cooperated with our detector to obtain higher SNR and sampling rate. Utilizing our near infrared spectrophotometric system, spectra were collected from 91 volunteers in vivo and divided into calibration set, two prediction sets to conduct clinical trials. Having compared results from two predicting tests, we optimized the best method DOSC coupled with PLS, and then discussed the precision and stability of non-invasive Hb concentration detection based on this method.

2. Device

The block diagram of near infrared spectroscopy non-invasive Hb detection system is shown in Fig. 1. This system consists of a light source (75 W tungsten halogen), a beam-splitting system, a detection system and a data acquisition system. The spectral range is from 1100 nm to 1400 nm, spectral sampling rate is 50 spectra per second, the repetitive SNR is better than 15,000:1.

2.1. Detection system

Due to the heartbeat, blood circulation and other physiological phenomenon existing, blood vessel size is varying over time. The variation will result in spectra obtained at different time corresponding to different optical path. G7150 InGaAs array detector produced by Hamamatsu Photonics Co., Ltd is adopted so that all spectra could be obtained at the same time and errors generated by scanning could be avoided. The detector consists of 16 independent InGaAs pixels, so that it could effectively avoid signal crosstalk. High detection sensitivity and frequency response further make it well meet fast and high SNR requirements of non-invasive Hb detection.

2.2. Amplification circuit

To cooperate with array detector for detecting weak signal, system of the whole amplifier circuit adopts 16 independent amplifier circuit schemes, which could effectively avoid inter-pixel crosstalk and reduce noise rather than the single amplifier and multiplex structure. As light intensity will be reduced by more than one order of magnitude after transmission, amplification circuit needs to reach to 10^9 that faint variation of the signal can be detected. To achieve this goal, the first order amplifying circuit with less noise introducing is utilized. Meanwhile, we adopt low-noise amplifier chips, low noise resistors and other precise components in our amplifier circuit and optimize the designs about printed circuit board arrangement and electromagnetic shielding device. Ultimately, we accomplish the high SNR amplification circuit system within 50 Hz bandwidth.

2.3. Beam-splitting system

Reflective plane grating is adopted as the spectral component, which could obtain spectrum with plane surface to match with array detectors well. Our beam-splitting system structure uses cross-asymmetric Czerny–Turner with excellent performance in weak signal detection. This asymmetric structure is compact that avails to control the stray light in system. Meanwhile, it also could control the coma aberration. Beam-splitting system consisted of a slit, a collimating mirror, a granting and focus mirror. The groove density of grating is 300 g/mm, the blaze wavelength is 900 nm.

2.4. Data acquisition system

We selected multi-function data acquisition card (DAQ) 6281 M from National Instruments for the acquisition module and developed data acquisition software for our spectrophotometric system. The relevant parameter settings of DAQ are shown as follows. Sampling rate is 2 k/s, collecting time is 20 s, 20,000 points per channel. When collecting data, the computer displays the measured spectral data onto the software interface synchronously. Then the operator determines whether measured data is ideal. If it is suitable we will end the acquisition process and save data. Otherwise, we will collect data once more.