33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

NIRS Study of Cerebral Oxygenation and Hemodynamics in Neonate at Birth

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Abstract—**To study the changes of cerebral oxygenation and hemodynamics in normal neonates at 2-5 min post-birth and understand the effects of pregnancy-induced hypertension (PIH) upon cerebral oxygenation and hemodynamics in newborn neonates. The near infrared spectroscopy (NIRS) was employed to measure the absolute quantity of brain tissue oxygen saturation (rSO2) in newborn neonates and the changes of concentrations of deoxyhemoglobin (Hb) and oxygenation hemoglobin (HbO2) with time relative to initial values to further obtain the changes of total hemoglobin (tHb) and cerebral perfusion (denoted by HbD). In normal neonates at 2-5 min post-birth, rSO2 increased while tHb remained relatively stable and HbD increased. In neonates born of PIH mothers at 3-5 min post-birth, the changes of tHb were markedly higher than those in the normal infants, $p<0.05$; at 2-5 min post-birth, the changes were markedly lower than the normal term infants. We concluded that NIRS can detect the changes of cerebral oxygenation and blood flow in a non-invasive and effective way.**

I. Introduction

During the birth of neonates, many perinatal factors such as blood pressure fluctuation, blood flow changes and vascular dilation & constriction, may cause hypoxic-ischemic changes of brain tissue and even the occurrence of brain injuries. Therefore understanding the physiological status of cerebral oxygenation and blood flow changes in neonates at birth and early detecting the abnormal changes will enable the clinicians to discover brain injuries timely and take therapeutic or preventive measures at an early stage so as to reduce the occurrence of nervous disabilities.

As early as 1949, the excitation of neuron was proved to be correlated with its photobiological parameters [1]. In 1977, Jobsis et al [2] reported that the near infrared light energy could penetrate the skull to obtain the information of oxygenation in human brains. The technology of near infrared spectroscopy (NIRS) is based upon the interactions between light and biological tissues. The near infrared light at the wavelengths of 650-950nm has excellent penetration for human tissues (reaching several millimeters under the skin). Within this spectral band, deoxyhemoglobin (Hb) and oxygenated hemoglobin (HbO2) are the major absorbing tissue substances and there is significant difference between the absorptive spectrum of them [3]. As compared with other technologies of detecting cerebral blood oxygen parameters, NIRS has the advantages of non-invasive, quantitative, real-time and non-interruptive [4]. However, the performance of NIRS method is not clear in the newborn neonates of several min post-birth. In this paper, we investigated the changes of Hb and HbO2 referring to a stable baseline (denoted as △Hb and △HbO2) and the absolute value of regional tissue oxygen saturation (rSO2) through detecting the attenuation of incidence light as relative to reflector light. By employing the NIRS oximeter developed by our group previously, the brain oxygenation and cerebral blood flow (CBF) dynamics were studied in this preliminary study.

Manuscript received March 26, 2011. This study is funded by the Fund of Juvenile Teacher in Doctoral Subject (200800011071).

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II. Method

A. Blood oxygen parameters of brain tissue

There are a large number of arterioles, veins and capillaries in brain tissues. rSO2 is the weighted mean of all the blood oxygen saturation values (venous blood 60-80%, arteriole blood 15-20% and capillary around 5%). The brain tissue rSO2 is fundamentally different from finger-tip pulse oxygen saturation (SpO2). When the local human brain tissue becomes hypoxic, the rSO2 is relatively lower while SpO2 can still stay at a normal level [5].

The total concentration of hemoglobin was the sum of Hb and HbO2. Based on the relative parameters measured by the NIRS method, namely △Hb and △HbO2, the changes of tHb could obtained as △tHb=△Hb+△HbO2. Delpy et al [6] proposed that △tHb reflected the changes of cerebral blood volume (CBV) in the tissues. Another relative parameter △HbD was the difference between △Hb and △HbO2, i.e., △HbD=△HbO2-△Hb. △HbD represents the perfusion status of brain tissue. In recent years, the animal studies of newborn pigs have demonstrated that the decrease of mean artery pressure induced the decrease of cerebral blood flow (CBF) and there was an excellent correlation between CBF detected by radioactive color micro-ball experiment and NIRS-measured HbD [7].

B. Instrument

The noninvasive NIRS oximeter (TSAH-100, Heifei Optic-electronic Co., Ltd, China) used in this study was based on continuous wave optical measurements of spatially-resolved spectroscopy. There are one dual-wavelength near infrared light source and two photoelectrical detectors. The illuminating wavelength of light source is 760nm and 850nm and the distances between two detectors and light source were 20mm and 30mm respectively. The oximeter and its prototypical sample machine (TSNIR-3) have passed the experimental calibrations of liquid model and proved to be accurate and reliable. Refer to our previous articles for more technical details [7-8].

C. Subjects

A total of 78 neonates were detected, including 64 neonates as normal control and 14 neonates with mothers complicated with pregnancy induced hypertension (PIH). The study protocol was approved by Ethics Committee of Peking University First Hospital. All the neonates had no postnatal asphyxia and there was no significant difference in the cord blood pH between the two groups. The birth fetal ages and body weights of neonates with PIH mother were markedly lower than those in the control group ($p<0.05$).

D. Data collection and processing

Data was collected immediately after the birth of neonates (1-5min post-birth). The sensors were placed upon the forehead. Sampling frequency was 0.5 Hz. Three hemodynamic parameters, i.e. △Hb, △HbO2 and rSO2 were recorded simultaneously from 1 to 5 min post the cord ligation. The data at the first min was considered as reference when relative measurements were calculated.

III. Results

Figure 1 displayed the hemodynamic changes in control groups. It shows that 1) rSO2 increased from about 40% at the 2nd min to approximately 60% at the 5th min post-birth; △tHb remained almost unchanged during 2-5min post-birth; △HbD increased from 5 μmol/L to above 30μmol/L .

Figure 2 displayed the hemodynamic changes in neonates with PIH mother. It shows that 1) although rSO2 was approximately 35% at the 2nd min post-birth, it increased in the following 4 min and reached a similar level as in control neonates; △tHb increased from 2 min to 4 min; △HbD increased from 3 μmol/L to above 20μmol/L .

The results in Figure 1 and 2 were statistically compared and summarized in Table 1. It shows that the △tHb in the neonates with PIH mother at 3-5min post-birth was significantly higher than that in the normal controls; the △HbD in the neonates with PIH mother at 2-5min post-birth was significantly lower than that in the normal controls ($p< 0.05$).

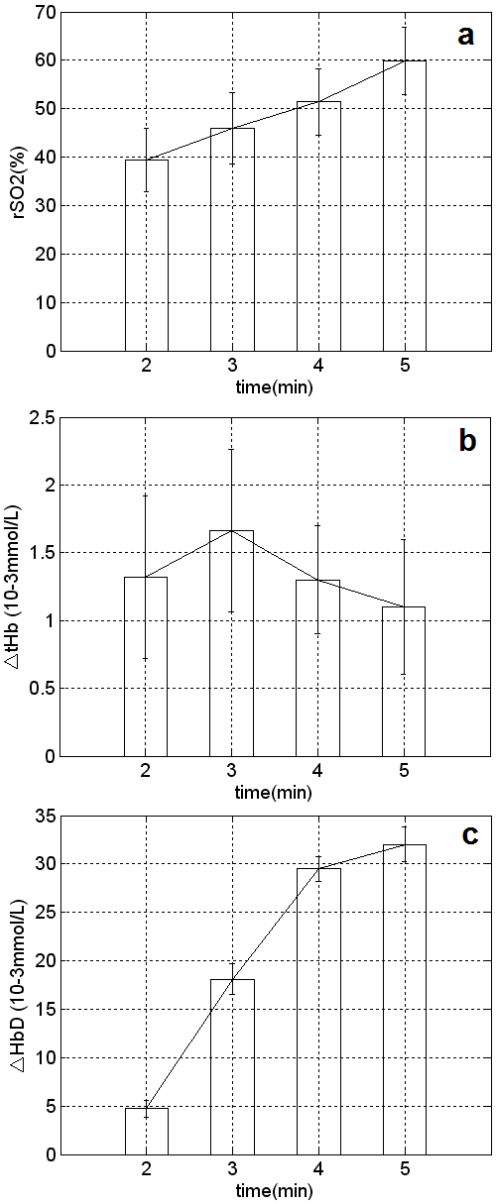

Fig. 1 Changes of oxygenation, blood flow and perfusion in control group. (a) brain tissue oxygen saturation; (b) the change of tHb; (c) the change of HbD.

IV. Discussion

It has been reported that the mixed gas of nitrogen and oxygen could cause hypoxia in healthy adult volunteers; the rSO2 decreased immediately once the concentration of the inhaled oxygen decreased; the changes in NIRS measurement occurred 113 ± 59s earlier than the electrocortical activity (i.e. EEG) [9]. Therefore, NIRS method can detect the hypoxia of brain tissue at an early stage while other monitored parameters may still remain in a normal range. It has been proved that the continuous detection of tHb changes could reflect the changes of cerebral blood volume (CBV); the continuous detection of HbD changes could reflect the changes of cerebral perfusion.

TABLE I
HEMODYNAMIC PARAMETERS IN NEONATES AT 2-5MIN POST-BIRTH

Time	rSO2(%)		ΔtHb ($\times10^{-3}$mmol/L)		ΔHbD ($\times10^{-3}$mmol/L)	
(min)	Control	Mother PIH	Control	Mother PIH	Control	Mother PIH
2	39.4±6.5	34.5±8.3	1.3±0.6	0.9±0.3	4.8±0.9	3.1±0.8*
3	45.9±7.4	41.3±7.9	1.7±0.6	4.0±1.2*	18±1.6	6.1±1.0*
4	51.4±6.8	53.9±8.8	1.3±0.4	7.0±2.6*	30±1.3	18±1.1*
5	59.9±7.0	59.2±6.8	1.1±0.5	7.5±3.2*	32±1.8	20±3.0*

* $p<0.05$ between two groups.

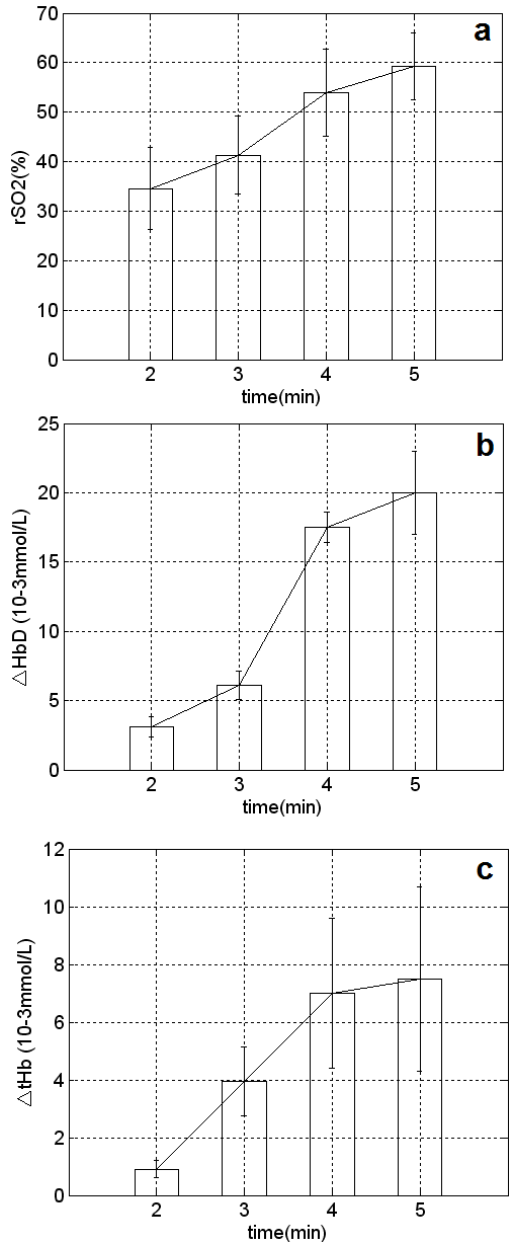

Fig. 2 Changes of cerebral oxygenation, blood flow and perfusion in neonates with PIH mothers. (a) brain tissue oxygen saturation; (b) the change of HbD; (c) the change of tHb.

At the birth of neonates, the uterine environment changes into the extra-uterine environment and the cord circulation is interrupted so the placental function of gas exchange is lost. Accordingly, the respiratory and circulatory systems of neonates change and develop rapidly in order to perform gas exchanges and meet the life-sustaining requirements. After the birth, various stimuli let neonates start breathing and crying. Regular respiration appears at 10s to 1min. With the establishment of respiration, brain tissues begin to transfer from the relative hypoxic status inside the uterine to normal oxygenation. It is showed in this study that the brain tissue oxygenation gradually increased during 2-5 min post-birth. At 5 min post-birth, the neonate brain tissue rSO2 reached as high as $59.9 \pm 7.0\%$, which is similar with the values reported by others [10-11]. The brain tissues then reached a steady state, since the oxygen supply and consumption go into a balance. As revealed in the result of normal neonates, the cerebral blood volume, which was indicated by △tHb, maintained at a stable level during 2 min to 5 min post-birth; whereas cerebral perfusion, which was indicated by △HbD, showed a rising trend. Thus the result reflected the cerebral oxygenation increase after birth.

PIH is a disease specifically occurred during pregnancy, usually after 20th week of pregnancy. The clinical manifestation was continued blood pressure increase accompanied with proteinuria and/or edema. The neonates given birth to by PIH mothers had 5 folds of morbidity and mortality rates of perinatal diseases compared with those in normal controls. In present study, the fetal ages and body weights of neonates with PIH mothers were markedly less than those in the control group. It was mainly because severe PIH is often associated with severe complications and obstetric accident such as pre-eclampsia, abruptio placenta, PIH heart diseases and multi-organ failure, which may cause acute hypoxia-ischemia (HI) in the fetus. If the HI is not handled timely, intra-uterine stillbirth or premature birth may happen.

We found that at 3-5 min post-birth, the △tHb in neonates with PIH mothers was significantly higher than that in the control group. The result indicated a compensatory increase of CBV may be caused by the insufficient intra-uterine fetal blood supply or chronic hypoxia. We also found that at 2-5 min post-birth, the △HbD in neonates with PIH mothers was significantly lower than that in the control group. It was probably caused by chronic intra-uterine hypoxia, the increased compensatory of red blood cell, slow blood flow or blood stasis.

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