Hemodynamic analysis of patients in intensive care unit based on diffuse optical spectroscopic imaging system

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ABSTRACT

Diffuse optical spectroscopic imaging (DOSI) is a technique to assess the spatial variation in absorption and scattering properties of the biological tissues and provides the monitoring of changes in concentrations of oxy-hemoglobin and deoxy-hemoglobin. In our preliminary study, the temporal tracings of hemodynamic oxygenation are measured with DOSI and venous occlusion test (VOT) from normal subjects, patients with heart failure and patients with sepsis in intensive care unit (ICU). In experiments, the obvious differences of hemodynamic signals can be observed among the three groups. The physiological relevance of VOT hemodynamics with respect to diseases is also discussed in this paper.

Keywords: Diffuse optical spectroscopic imaging, vessel occlusion test, intensive care medicine.

1. INTRODUCTION

In intensive care medicine, real-time physiological monitoring of vital sign plays an important role in diagnosis and therapy, especially for cardiovascular insufficiency assessment for critical patients with heart failure or sepsis. Patients with cardiovascular insufficiency can induce increased sympathetic output that attempts to maintain central blood pressure and vital organ perfusion by vasoconstriction of lesser vital organs and muscles in intensive care unit (ICU). The compensatory mechanisms could mask profound hypovolemia. Currently, the bedside assessment of cardiovascular adequacy is limited to measures of vital signs, blood lactate and capillary refill, and to invasive hemodynamic monitoring [1]. Therefore, any information that characterizes tissue oxygenation with non-invasive measurement can be of great help in ICU.

Over the past decade, diffuse optical spectroscopic imaging (DOSI) with near-infrared light assessment has been shown to be an effective tool for measuring local changes of tissue in hemodynamics. Diffuse photon (the propagated photon with multiple scattering in tissue) can penetrate several centimeters through the tissue to measure the difference in the concentrations of oxy-hemoglobin (HbO_2) and deoxy-hemoglobin (Hb). It has been utilized for the assessment of muscle perfusion since 1986 [2-4]. In order that the use of an exogenous tracer was avoided, the analysis of the abrupt changes of HbO_2 and Hb after vascular occlusion has been proposed [5]. The technique has demonstrated a good correlation with xenon and plethysmography methods, both in resting and exercising subjects [6]. The increase of tissue blood volume during vascular occlusion can cause an optical absorption variation. Thus, the signal of tissue oxygenation can be optically measured. In our study, a continuous-wave (cw) DOSI system was built with dual-wavelength laser diodes (LDs) as near-infrared light sources. We hypothesized that non-invasive monitoring the dynamic response to

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tissue oxygenation during a venous occlusion test could characterize local metabolic rate and local tissue perfusion adequacy and tissue O_2 saturation recovery behavior from venous occlusion would reflect pre-existing cardiovascular reserve. The study preliminarily reported the muscle oxygenation in the human extremity measured during vessel occlusion test in normal subjects and ICU patients with septic shock and heart failure.

2. METHODS

The DOSI setup included four pairs LDs (QL78D6S and QL85D6S, QSI) that were used as light sources at 780 and 850 nm. The backscattered optical signals from human tissue were detected by nine photodiodes (TSL13T, TAOS) that were arranged as four squares on a flexible probe and the light sources were placed on the centers of squares, respectively. The data acquisition card (DAQ) was used for PC-optode interfacing that contains LDs driving, multiplexing and detected signals demultiplexing from photodiodes. All of the optical signals are analyzed based on the modified Beer-Lambert law with various source-detector separations on optode.

Although the induced ischemia process (arterial occlusion test) provides information of local muscle energy metabolism [7,8], however, this process takes a risk for critical patients in ICU. Thus, the VOT was adopted to estimate muscle oxygen consumption and muscle blood flow by applying the same technique used in conventional venous plethysmography [9]. A controllable pneumatic tourniquet offers 50 mmHg on upper arm for venous occlusion and the optode of DOSI is placed on brachioradial muscle for extremity metabolic assessment based on optical detection. The clinical study was designed as a prospective case-controlled clinical investigation and informed consent was obtained from normal volunteers and waived for patients. In the preliminary study, two patients with sepsis and two patients with heart failure were measured in ICU. Two healthy volunteers were treated as control subjects. Generally, temporally applied low cuff pressures (50 mm Hg in our cases) occlude venous outflow while minimally obstructing arterial outflow. The increase in deoxygenated blood is then used to calculate muscle oxygenation [10]. Near-infrared spectroscopy determined assessments of tissue oxygenation by VOT have been shown to agree with traditional measurements using plethysmography and the Fick method [11]. The traditional measures cannot provide localized detections on muscle tissue, however, DOSI offers an ability to access the spatial distribution of tissue oxygenation in real-time [12]. Subjects were placed in a quiet environment while resting in a semi-recumbent position and no movement was allowed during the optical measurements with VOT. An initial manual blood pressure assessment was taken on the same arm to define baseline perfusion pressure using a sphygmomanometer. The sphygmomanometer was then placed on the forearm above the probe to minimize both discomfort during VOT and total vascular space from which blood volume redistribution might occur [13]. During the DOSI measurement, several physiological parameters (heart rate, respiratory rate, FiO_2, SpO_2, etc.) were monitored for safety (shown in Table 1).

Table 1. Physiological parameters of DOSI subjects.

	h A	h B	s A	s B	n A	n B
Age (years)	67	72	45	42	23	23
MAP (mmHg)	98	67	66	55		
HR (beats/min)	94	97	111	93		
RR (breaths/min)	12	20	27	25		
FIO_2 (%)	30	30	40	100	21	21
SPO_2	99	97	100	69		
Hemoglobin (g/dl)	9.5	9.7	6.6	8.7		

3. RESULTS

Figure 1 demonstrates temporal tracings of tissue O_2 saturation (StO_2), total hemoglobin (THb), oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) response to a VOT from a group of normal control. The THb signal indicating the local blood volume of tissue is increased during the VOT process. The StO_2 response is then co-varying with the hemodynamic variation. The experimental data from healthy volunteers supports the results of previous studies [14].

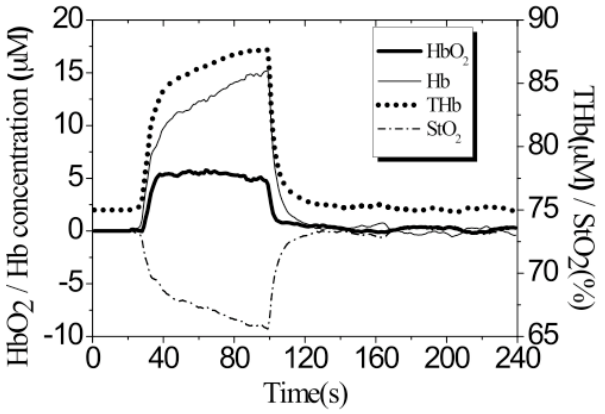

Figure 1. Temporal tracings of a normal control tissue O_2 saturation (StO_2), total hemoglobin (THb), oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) response to a VOT assessment.

Figure 2 shows the HbO_2/Hb responses to VOT of heart failure patients. Obviously, the hemodynamic response of heart failure is lower than normal subject. This result implies the heart failure patients exhibited less deoxygenation or oxygenation compared with the controls, due to the pump failure of the heart and the consequent skeletal muscle hypoperfusion [15]. The hemodynamic tracings reveal stepwise patterns of increasing/decreasing of Hb and StO_2 in patients with heart failure.

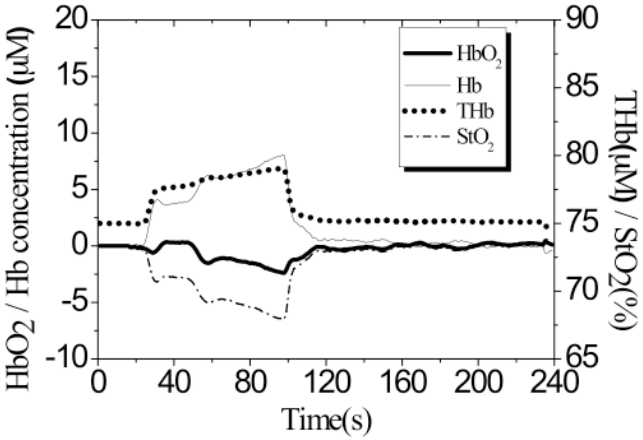

Figure 2. Temporal tracings of the VOT response of a heart failure patient.

4. DISCUSSIONS

For qualitative comparison, the highest amplitude of hemodynamic change occurs at the beginning of VOT in healthy subjects, especially in change of oxy-hemoglobin concentration. Besides, the increasing patterns of deoxy-hemoglobin concentration are quite different between normal and patients. As mention before, different patterns reveal the different physiological conditions in subjects. On the other hand, the recovery time of total hemoglobin is much longest in septic

patients. Although the preliminary study measured the hemodynamic signals during VOT with few of subjects, the results indicate high feasibility of clinical diagnosis based on DOSI method in ICU. We are going to collect and analyze more clinical data for the further understanding.

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