Hemoglobin Detection in Opaque Particular Fluids

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Abstract

A measurement system for free hemoglobin in opaque particular liquids was developed. Sophisticated systems for specific toxin removal in extracorporeal blood purification are based on particular adsorbent suspensions. In case of treatment problems (too high shear forces to erythrocytes) red blood cells are damaged and hemoglobin is released. To protect patients from red blood cell damage, a detection device for fHb is needed. A spectroscopic fHb measurement system was developed and tested based on light reflection/scattering on the particular suspension.

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1. Introduction

Plasmapheresis and hemoperfusion/plasmaperfusion are detoxification methods that are mainly designed to remove protein-bound or hydrophobic substances from the blood. Nevertheless, the mortality and morbidity of patients suffering from acute or chronic liver failure can be improved by eliminating toxins from the blood which cannot be eliminated using conventional dialysis treatment (hemodialysis, hemofiltration) which removes only water-soluble substances [1-5]. We considered, therefore, developing a new, inexpensive detoxification method which is both effective and selective in its elimination of hydrophobic and protein-bound substances from the blood based on suspended micro adsorbents. The Microsphere based Detoxification System (MDS) [6-10] is a device consisting of two circuits connected through a hollow-fiber membrane filter (fig. 1). The suspended microparticles, circulating in the secondary circuit, can be modified to satisfy various medical requirements by adding different functional
groups to the adsorptive outer and inner surface structures for selective removal of toxins. If the transmembrane pressure in the plasma filter is too high, the red blood cells can be damaged due to high shear forces and therefore hemoglobin is released. To protect the patient from erythrocyte damage, a detector for free hemoglobin (fHb) must be placed in the secondary MDS circuit.

Fig. 1. Functional principle of the microparticle based detoxification system (MDS).

2. Sensor design

In standard plasmapheresis systems, the liquid in the filtrate circuit is transparent where fHb can be easily detected by measuring the redness of the media. The redness measurement is typically done by calculation of the absorbance ratio of red and green light during transmission through the media according to the Lambert–Beer law. As more hemoglobin is present in the filtrate, as higher becomes the absorbance of red light during transmission and therefore the absorbance ratio between red and green light changes. Typical fHb detectors used in commercial plasmapheresis devices have an fHb alarm threshold of 150mg fHb per dl plasma [11]. The developed optical detection system is designed to measure the content of fHb in an optical opaque media like in the MDS sorbent circuit. The sensor principle is based on spectroscopic measurement of reflected/back scattered light under broad band illumination (400 to 700nm) of the adsorbent microparticle suspension [12]. The tubing containing the microparticle suspension is fixed in a sensor housing (fig. 2) where it is compressed and flattened in the measurement chamber.

Fig. 2. Principle of the optical fHb sensor.

Legend:
1 White measurement LED
2 Green control LED
3 Aperture
4 Glass panel
5 Tubing system
6 Particular suspension
7 Housing
8 Door
9 Emitted light beam
10 Reflected light beam
11 Optical fiber to the micro-spectrometer
At the rear of the housing a white and a green LED light source as well as a tip of a glass fiber for collecting the reflected light is placed. The white light source is used for an optical broad band illumination of the suspension and the green light source is used for an internal system life/dead test at startup. Emitted light passes through the transparent tube wall into the optically dense liquid in the tubing and is absorbed, reflected or scattered, depending on the given wavelength. Reflected light from the suspension is collected by a collateral placed glass fiber and directed to a spectrometer. During MDS treatment, cyclic spectral measurements for fHb detection are done by spectral measurement of the “dark spectrum” (all LEDs off) and subsequent spectral measurement of the reflected/scattered light from the suspension carrying tubing under illumination of the white measurement LED. The output signal for fHb detection $S$ at a certain wavelength $\lambda_n$ and at the $k^{th}$ measurement cycle is calculated by eq. 1 and shown in fig. 3.

$$S(\lambda_n, t_k) = \log \frac{\theta_{\text{Measurement}}(\lambda_n, t_k) - \theta_{\text{Dark}}(\lambda_n, t_0)}{\theta_{\text{Measurement}}(\lambda_n, t_0) - \theta_{\text{Dark}}(\lambda_n, t_k)}$$

The detected light intensity at the spectrometer $\theta(\lambda_n, t_k)$ is measured at the wavelength $\lambda_n$ and at the time point $t_k$ where the $k^{th}$ measurement cycle is running. For calibration, the measurement spectrum and the dark spectrum at start up (time point $t_0$) is used. After spectral measurement, the spectral values between 520nm and 600nm are summarized building the output signal $G(t_k)$ (eq. 2) which is linear proportional to fHb content in the suspension (fig. 4).

$$G(t_k) = \sum_{\lambda=520nm}^{600nm} S(\lambda_n, t_k)$$

### 3. Conclusions

A method for optical detection of fHb in opaque particular liquids has been developed. The system design is based on spectral measurement of back scattered/reflected light. By integrating the spectrometer output signals in the wavelength range from 520nm to 600nm an approximately linear relation to the fHb content
was found. Typical fHb detectors used in commercial plasmapheresis devices have an fHb alarm threshold of 150mg fHb per dl plasma which is also clearly achieved by our device.

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References


