DETERMINATION OF OPTICAL PROPERTIES OF HUMAN BLOOD TO DEVELOP NEW DEVICES FOR BLOOD MONITORING

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Abstract: **The micro-optical parameters of human blood i.e. absorption coefficient μ_a, scattering coefficient μ_s and the anisotropy factor g which depend on the physiological parameters haematocrit, oxygen saturation, osmolarity and haemolysis, were determined for the spectral range 400 nm to 1000 nm. These parameters were used for the calculation of light distribution in blood to develop a new device for monitoring hematocrit and oxygen saturation of blood used in extracorporal circulation for cardiopulmonary systems.**

Keywords: **optical properties, blood, extracorporal circulation, scattering, absorption**

Introduction

Knowledge about the micro-optical parameters of human blood i.e. absorption coefficient μa, scattering coefficient μs and anisotropy factor g, and their dependence on physiological parameters such as haematocrit, oxygen saturation, osmolarity and haemolysis plays an important role in many diagnostic and therapeutic applications in laser medicine and medical diagnostics. To calculate the light distribution in blood perfused tissue, information is required about the optical properties of blood for a number of optical methods, such as optical tomograghy, optical biopsy, photodynamic therapy and laser-induced thermotherapy. Furthermore the optical parameters can be used for the quality control of blood products and the monitoring of extracorporal circulation of blood in cardiopulmonary systems. This paper presents an application related to the last field.

Materials and Methods

The macroscopic optical parameters, diffuse backscattering R_d, the total transmission T_t and the diffuse transmission T_d, of circulating human blood were measured under various physiological conditions in the spectral range of 400-1000 nm using the integrating sphere technique [1]. The special turbulence free cuvette used was 0.116 mm thick. Inverse Monte Carlo simulations were applied to determine the micro-optical parameters μa, μs and g [2].

The micro-optical parameters were used for the calculation of light distribution in blood to develop new devices for the quality control of blood or for monitoring haematocrit and oxygen saturation of extracorporal circulation in cardiopulmonary systems.

For example, a functional model including an integrating sphere was developed and is shown in Figure 1. Light from a white light source was passed into an optical system which focussed the beam through the sphere on the cuvette filled with the continuously flowing blood. The back-scattered light was collected in the sphere and transferred through a bare fiber to the spectrometer.

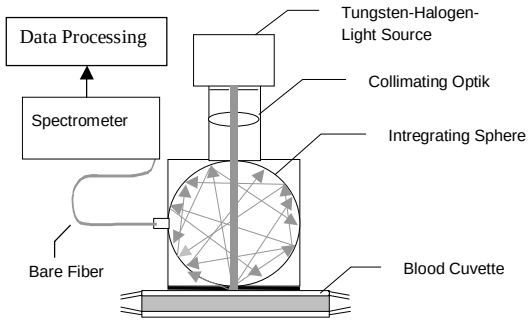

Figure 1: Schematical illustration of a functional model for measuring haematocrit and oxygen saturation in extracorporal circulation systems.

This functional model was adapted for an extracorporal circulation system and the remission spectra were recorded for various hematocrit and oxygen saturation values which were changed simultaneously. The measurements with the functional model were made under clinical conditions. The prediction of blood parameters was investigated after application of multivariate regression, such as principal component regression (PCR) and the partial least square (PLS) [3]. In two test series the experimental parameters: blood flow, haematocrit (HCT), and oxygen saturation ($SatO_2$), were changed.

Results

The optical parameters were determined in the wavelength region 400-1000 nm for circulating blood for different concentrations of red blood cells (0,2-5,0 mill/μl), various degrees of oxygen saturation (60-100%), osmolarity (225-400 mosmol) and haemolysis (0-100%). Each particular blood parameter affects the optical parameters in a different way. The optical parameters in the spectral range 400 to 1000 nm for various red blood cell concentrations are shown in Figure 2.

The red blood cell concentration influences the absorption as well as the scattering behaviour of blood. For selected wavelengths there are linear dependencies for each blood parameter.

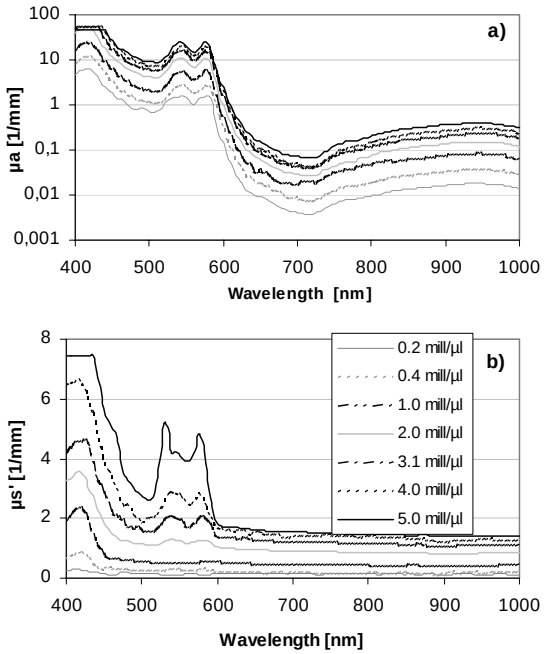

Figure 2: Absorption coefficient (a) and reduced scattering coefficient (b) in the spectral range 400 to 1000 nm for various red blood cell concentrations.

Using the functional model for measurements on extracorporal circulation systems two test series were derived. In the first the experimental parameters blood flow (2 - 5 L/min), haematocrit (HCT: 20%, 35% and 50%); oxygen saturation ($SatO_2$: between 70% and 100%) were systematically changed. The second test series was derived with reduced flow rate 0,2 - 0,5 L/min, the prepared HCT values were 25%, 30%, 35% and the oxygen saturation was in the range of 80% to 100%.

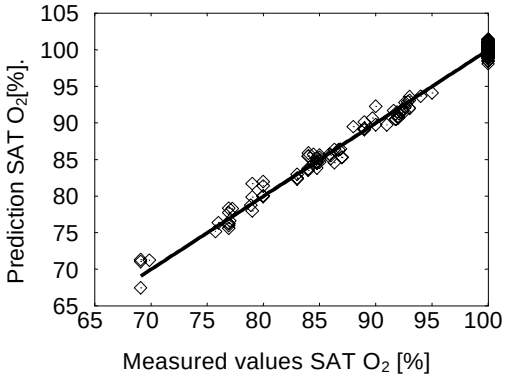

Figure 3: Prediction of oxygen saturation compared to measured values $SatO_2$, PRMSE: 0,9 %, n_p: 4, n_{dat}: 150

The predicted oxygen saturation values with PLS compared with the experimentally adjusted $SatO_2$ values, taking both test series into the calibration, are shown in Figure 3. 150 spectra (n_{dat}) were collected and evaluated with PLS. The predictive root mean square errors (PRMSE) is 0.9% (4 principle components (n_p)). The PRMSE for oxygen saturation and haematocrit for the first two test series are shown in Table 1.

Table 1: Predictive root mean square errors of predicted oxygen saturation and haematocrit values.

Nr.	Test series	SatO2 %	HCT %
1	1	0.8	1.5
2	2	0.7	0.9
3	1+2	0.9	1.3

Discussion

The determination of the optical parameter of blood presented here is a very powerful tool to calculate the light distribution in blood under various geometrical conditions and for different light sources. Computer simulations based on these data make the development of new methods and devices for optical measurement on blood both easier and quicker.

The PRMSE of the values measured with the presented functional model for extracorporal circulations systems are much smaller than those of comparable optical measuring products currently on the market. The PRMSE for both blood parameters are in the range of the standard deviation of the laboratory reference methods.

Conclusions

The determination of the optical parameters of human blood i.e. absorption coefficient μa, scattering coefficient μs and anisotropy factor g, have shown that there is a strong dependency on physiological parameters haematocrit, oxygen saturation, osmolarity and haemolysis.

The results have shown that it is possible to construct a new non-invasive device based on an integrating sphere which is able to predict the blood parameter HCT and $SatO_2$ by remission measurements with consequent evaluation of the data using chemometric algorithm PLS with an PRMSE less than 2%.

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