Non-invasive estimation of hematocrit by means of Power Doppler attenuation measurements

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I. INTRODUCTION

Non-invasive, continuos methods of measurement of hematocrit are recently developed. Such monitoring is especially useful for patients in the post-traumatic shock, during open-heart surgery and those managed with dialysis. The recent literature provides report of Johner et al. [3] on ultrasonic monitor for continuos measurement of hematocrit. Change of velocity of ultrasonic wave propagation in the blood plasma depending on red blood cell count has been used in this device. The obtained results are assessed enthusiastically as a correct consistency in relation to laboratory findings has been achieved. Unfortunately, use of this device is limited to *in vitro* measurements, i.e. for extracorporeal blood flow.

The proposed system for non-invasive determination of hematocrit is based on the ultrasonic Doppler blood flowmeter. Pulse flowmeters allow to record velocity of blood flow at selected depth, in determined sample volume.

Power of the Doppler signal is recorded simultaneously in two sample volumes Q_1 and Q_2 at two different depths. Two values of Doppler power proportional to the backscattering of the red cells at both depths may be obtained. It is assumed that the hematocrit in both gates is identical and therefore the difference of the backscattered power results only from the attenuation of ultrasonic wave at the distance equal to double distance between two sample volumes. Attenuation coefficient may be calculated from the formula:

$$\alpha = \frac{\ln(P_{Q1}/P_{Q2})}{4z} \qquad (1)$$

in which P_{Q1}, P_{Q2} - power of backscattered ultrasound in the gates Q_1 and Q_2, α - attenuation coefficient, z - distance between both gates.

II. MEASUREMENTS *in vitro*

Determination of exact value of attenuation coefficient is necessary for calibration of developed system. Many authors, among them by Carstensen [1] and Hughes [2] have performed measurements of ultrasonic attenuation. These authors carried out the studies using frequency of 10 MHz and below. The blood samples with various hematocrit were prepared by separation of blood cells from the plasma followed by mixing them in different proportion. The aim of this study was to estimate the average attenuation of ultrasound in series of blood samples taken from different patients.

The special container was designed and constructed for measurements of small amounts of the blood (Fig. 1). A plastic test-tube was placed inside a metal cylinder connected with thermostat. Ultrasonic transducer was mounted in the wall of the test tube. A steel ball serving as a reflector of acoustic wave was positioned across from the transducer. A small agitator driven with gearmotor was introduced from above. The vessel ensured a stable temperature 37°C ± 0.5°C and continuous stirring of the 1-2 ml blood sample.

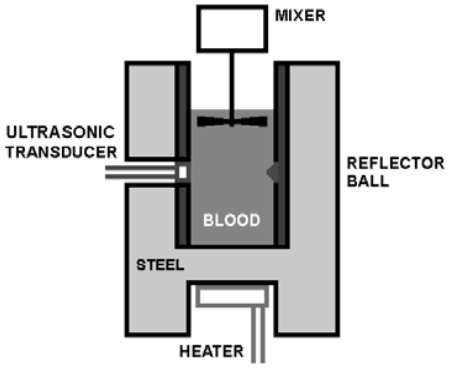

Figure 1: Cross section of the measuring container.

168 measurements of blood samples were carried out. The samples were taken from 30 females and 138 males aged 19-54. In addition, measurements for 5 samples of the plasma and separated blood cells were performed. Determinations of hematocrit were carried out using the automatic hematocrit analyzer Sysmex K-4500. Amplitude of the echo was acquired using digital oscilloscope. Each blood sample measurement was preceded by the calibration of the system in the distilled water.

III. RESULTS *in vitro*

No correlation of results with gender and age of patients was noted. The dependence of attenuation of ultrasonic wave on hematocrit is shown in Fig. 2.

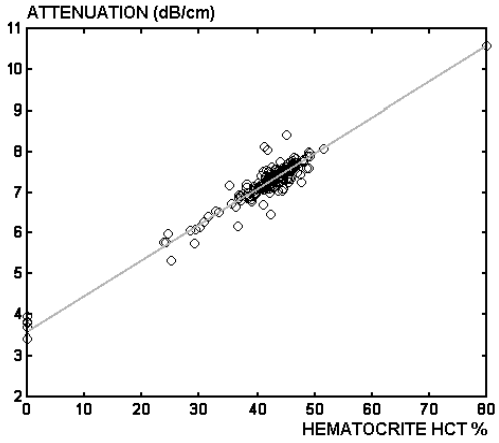

Figure 2: The dependence of attenuation on hematocrit

It presents results of measurements for samples of whole blood, plasma and separated blood cells (for which the estimated HCT=80%). Attenuation increases in proportion to hematocrit according to the formula: $\alpha = 3.61 + 0.087$ HCT (dB/cm). The standard error of estimate was SD = 0.21dB/cm

and the correlation coefficient was equal to R = 0.90 and p<0.001.

Measurements for separated blood cells and plasma were not considered in calculations of above-mentioned values.

IV. MEASUREMENTS *in vivo*

In the second part of the study, attenuation of ultrasound in the blood was measured *in vivo*. Multigate (64 gates) pulse Doppler flowmeter, being developed at the University of Florence, Italy, was used in the experiments [4]. 64 gates were equally distributed along the depth of 3-9.6 mm. The distance between gates was equal to 0.1 mm. The angle between the ultrasonic beam and direction of flow was close to 45°. A flat 20 MHz ultrasonic transducer of 3 mm diameter was used. Sample volume was equal to 2.5 mm in diameter and 0.3 mm in length. The ultrasonic beam is practically homogenous along the distance 3 - 12 mm from surface of the transducer.

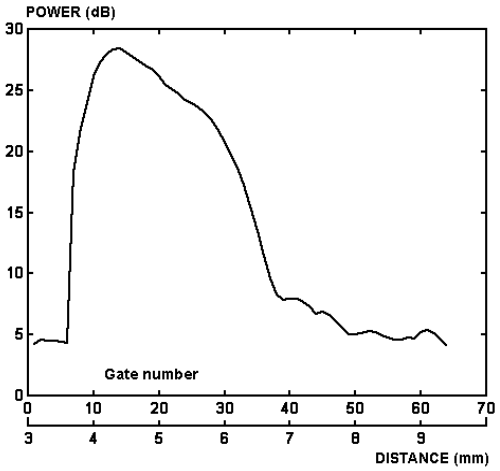

Figure 3: Power profile across the radial artery.

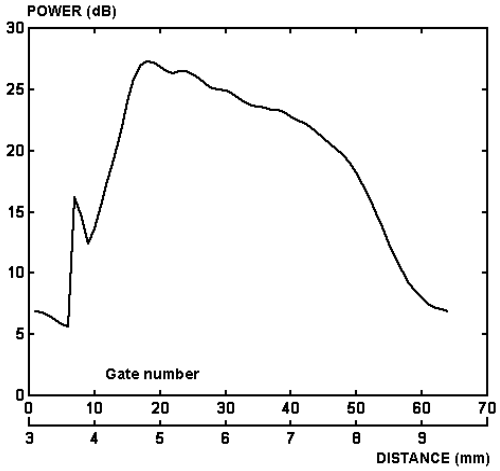

Figure 4: Power profile across the brachial artery.

The blood flow velocities were recorded in radial, brachial and common carotid arteries of each patient. 250 profiles were recorded during the period of 2.5 s. Each velocity profile included 64 FFT spectra recorded simultaneously in 64 adjacent gates. Doppler backscatterd power profile across the artery was computed and next the same algorithm as for two gate system was applied enabling calculation of the hematocrit.

V. RESULTS *in vivo*

Backscattered Doppler power recordings across the vessel are shown in Fig. 3 and Fig. 4. Each figure exhibits the mean value of the 16 power profiles. As backscattering of ultrasonic wave in the blood is random by nature, distinct changes of signal power for each profile were observed. To determine attenuation, linear regression coefficients were calculated separately for each power profile. Then 16 - 24 values were averaged. The Doppler data were acquired from the area located in the central part of the vessel cross section, 4.4 – 6.0 mm for radial and 4.8 – 7.2 mm for brachial artery. Values of attenuation were 8.74 dB/cm for radial artery and 7.53 dB/cm for brachial artery, corresponding to 59% and 45% hematocrit, respectively. In the common carotid artery, the signal to noise ratio was insufficient to obtain the correct results of measurements. Laboratory measured value of hematocrit for the patient was 42%. The measurements were carried out in 6 patients with hematocrit between 42% and 46%. Measurements in the brachial artery gave results consistent with laboratory findings with the accuracy of ± HCT (5%).

VI. SUMMARY

This paper presents a new system of hematocrit measuring instrument being designed for non-invasive measurements. It has been proven that attenuation increased in linear proportion to hematocrit. Standard deviation SD = 0.21 dB/cm for 20 MHz resulted in accuracy of measurement of hematocrit limited to ± 3.5% HCT. A series of *in vivo* measurements of hematocrit were carried out. Cross-sectional blood flow power profile and dependence of the Doppler signal power on the depth were recorded. The best results were obtained for the brachial artery. Attenuation and then hematocrit were determined after averaging of the Doppler signal power. An absolute accuracy of measurement was ± 5% HCT. This value is sufficient to monitor changes of hematocrit in patients in shock or during hemodialysis.

ACKNOWLEDGMENTS

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