OPTICAL MIXING SPECTROSCOPY IN EVALUATION OF THE MICROCIRCULATION

I. M. Aref'ev and A. P. Es'kov

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The spectrum (correlation function) of laser light scattered on moving objects in a biological system contains information on the kinetics of these objects and can be used for medical diagnostic purposes. Stern [4] first showed experimentally that the spectrum of scattered laser light in the skin can be used to evaluate the microcirculation of blood *in vivo*. Watkins and Holloway [5] developed this method and constructed an instrument for clinical use. The advantages of the new method include the rapidity of obtaining information and the noninvasive character of the technique. This last advantage, however, is cited without experimental confirmation. Meanwhile in other experiments [4] a 15-mV helium–neon laser was used; since this illuminated an area of skin 1 mm in diameter, the luminous energy E on the object was about 2 W/cm^2. This is an order of magnitude higher than the maximal allowable level of irradiation of the skin for exposure longer than 10 sec [3]. Consequently, it is close to the level of thermal injury to the skin and may induce vascular reactions. Using a method of rheoplethysmography, Aleksandrov et al. [1] observed vascular reactions in the pharyngeal mucosa of dogs exposed to light from a helium–neon laser with luminous energy of 0.10 ± 0.22 W/cm^2.

In the investigation described below the optical mixing spectroscopy (OMS) method was used in a correlation variant to study vascular reactions in human skin to a low-intensity laser beam.

EXPERIMENTAL METHOD

A laser correlation spectrometer [2] with 48-channel K-7023 digital correlator (from Malvern Instruments, England) was used. A finger (index, middle or ring) of the right hand was fixed in the place of the cuvette chamber. The beam of a helium–neon laser (wavelength 0.633 μ), 1.1 mm in diameter and with maximal power of 5.8 mW, was directed on an area of skin on the palmar surface of the terminal phalanx. Light scattered at an angle of about 120° relative to the direction of the incident beam was recorded. This light consists of light scattered on stationary tissues and light scattered on blood flows in the capillaries. In the first case the frequency of the light is unchanged, in the second case it is altered by an amount which depends on the orientation of the capillary relative to the incident light and the direction of scatter and is proportional to the velocity of blood flow (Doppler effect). These signals are displaced on the photocathode of the scattered radiation receiver (a photoelectric multiplier), so that a component at the displacement frequency appears in the low-frequency spectrum of the photocurrent. In a real situation, as a result of repeated scatter in the surface layer, light falls on the capillaries at different angles; the capillaries themselves, moreover, are oriented in different directions, and for that reason the integral spectrum of the photocurrent consists of a continuous distribution with maximum at zero frequency, similar in shape to exponential [5], and with a half-width proportional to the mean velocity of blood flow.

In this investigation measurements were made of the spectrum and its Fourier transform – the correlation function. If the spectrum was exponential, the correlation function was described by a dispersion curve, and vice versa. Since the limbs of the exponential and dispersion curves are close together, the experimental points of the correlation fucntion $g(lT)$ were approximated by the exponent $\exp(-\Gamma lT)$, where l is the channel number of the correlator,

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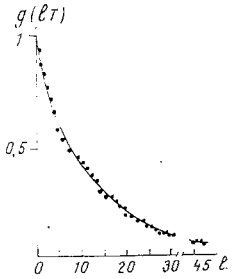

Fig. 1

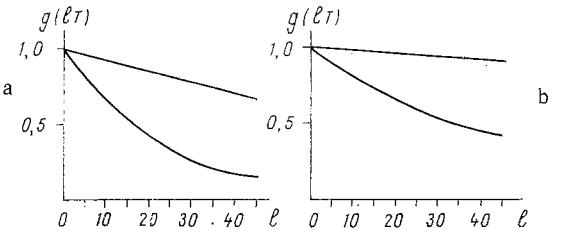

Fig. 2

Fig. 1. Correlation function g(ℓT) of photocurrent induced by light scattered in skin of finger (points) and exponential curve approximating it. Sampling time T = 10 μsec; ℓ) correlator channel No.

Fig. 2. Reduced normalized correlation functions g(ℓT) of photocurrent induced by light scattered in skin of healthy human finger. a) Under ordinary conditions (bottom curve); $\Gamma = 4.5 \cdot 10^3$ rad/sec and with tourniquet applied to forearm on side of investigation (top curve; $\Gamma = 750$ rad/sec); and also of a healthy subject (b — bottom curve; $\Gamma = 2 \cdot 10^3$ rad/sec) and of patient with angiospasm (top curve; $\Gamma = 225$ rad/sec): T = 10 μsec; ℓ) correlator channel No.

T the sampling time, $\Gamma/2\pi$ the half-width of the corresponding spectrum (in Hz), and they were processed by the method developed previously [2], to obtain the value of Γ. Knowing Γ it is possible to estimate the mean velocity of the blood flow v by the equation $v = \Gamma/q$, where q is the vector of scatter. For visible light $q = 10^5$ cm^{-1}. If $\Gamma = 10^4$ rad/sec we thus have v = 1 mm/sec, and so on.

Subjects (including the authors of this paper) aged from 18 to 42 years (six women and five men) took part in the investigations.

At maximal power of the laser beam the signal accumulation time was 10 sec, and the recording time of the signal on punched tape also was 10 sec. Allowing for time spent in switching over the correlation function was recorded every 23 ± 25 [sic] sec. The power of the beam was attenuated by means of neutral NS2 and NS3 filters.

EXPERIMENTAL RESULTS

A typical measured correlation function and the exponential curve approximating it are illustrated in Fig. 1. The value of Γ for the subjects taking part in the tests varied between 10^2 and 10^4 rad/sec. This corresponds to mean blood flow velocities of 10^{-2}-1 mm/sec. It will be clear from Fig. 2a that the signal measured is related to the volume of blood in the skin. To assess the contribution of low-frequency fluctuations of acoustic nature to the observed correlation function, the signal evoked by light scattered by the surface of a thin Porolon film, fitted tightly on the finger, was recorded. The value of Γ in this case was about 50 rad/sec, corresponding to frequencies of the order of 8 Hz.

The signal recorded depends on the depth of penetration of the laser beam into the skin which, in each concrete case, is determined by the luminous energy. Data showing dependence of the value of Γ on the luminous energy E for subjects with the maximal value of Γ are given below.

Dependence of Value of Γ on Luminous Energy E

E, W/cm^2	0,60	0,07	0,01
$\Gamma \cdot 10^{-3}$, rad/sec	10,0	4,1	1,2.

The data in Fig 2b and Table 1 illustrate the diagnostic value of the OMS method. In a patient with angiospasm the correlation curve was about 1 order of magnitude wider than that of a healthy subject.

Vascular reactions during continuous irradiation by a laser beam of maximal power were investigated in eight subjects (Table 2). In six cases the value of Γ was increased by 1.5-3

TABLE 1. Effect of Ethanol on Value of Γ for Two Subjects

Time after taking 50 g ethanol, min	$\Gamma \cdot 10^{-3}$, rad/sec	
	1	2
0	2,2	0,1
5	3,3	1,0
15	3,6	1,4
20	3,1	3,0
30	3,2	5,2

TABLE 2. Dependence of Γ on Duration of Irradiation when E = 0.6 W/cm^2

Duration of irradiation, min	$\Gamma \cdot 10^{-3}$, rad/sec							
	1	2	3	4	5	6	7	8
0	2,0	0,4	1,4	1,1	0,2	2,6	3,6	10,0
1	3,4	0,9	0,8	1,2	0,3	2,2	3,6	15,4
2	4,6	1,0	1,0	3,4	0,4	2,4	7,0	18,6
3	4,8	1,3	0,8	4,5	0,5	2,8	10.2	14,0
4	3,4	1,2	0,4	3,4	—	4,1	7,8	16,9

times at the 1st-2nd minute of irradiation, evidence of an increase in the blood flow velocity; in one case (Table 2, column 3) there was a decrease in Γ and in one case (Table 2, column 6) there was no observable effect. With a decrease in power of the laser beam the vascular reactions became less marked.

These investigations thus confirm the diagnostic value of the OMS method for evaluating the microcirculation *in vivo*. Meanwhile, when the OMS method is used allowance must be made for vascular reactions to the action of the laser beam. The OMS method can play an essential role in the study of the mechanism of action of low-intensity laser radiation during laser therapy and application of the laser beam to biologically active points, and when determining and confirming maximal allowable levels of laser irradiation of the skin, mucous membrane, and other organs and tissues.

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