VISUALIZATION OF THE BLOOD MICROCIRCULATION PARAMETERS IN HUMAN TISSUES BY USING THE TIME-INTEGRATED DYNAMIC SPECKLE ANALYSIS

Maria M. Gonik, Alexander B. Mishin, Dmitry A. Zimnyakov

Saratov State University, Astrakhanskaya st., 83, Saratov, 410026, Russia

Measurements of contrast of speckle pattern images captured with varying exposures allow to analyze the decorrelation of temporal fluctuations of speckle intensity and to evaluate the dynamic properties of the scattering system. This approach is known as laser speckle contrast analysis, or LASCA technique. Contrast estimations for the fragments of time-integrated images in the dependence on the exposure time allow to reconstruct 2D distributions of the average level of blood perfusion ("microcirculation maps"). Here we consider the modification of the full-field speckle technique, which is based on the application of the localized light source in combination with the speckle contrast analysis of time-integrated dynamic speckle patterns. Such approach gives certain opportunities for depth-resolved analysis of the blood microcirculation parameters.

INTRODUCTION

Various applications of laser Doppler methods for blood flow monitoring have become one of the universally adopted and rapidly developing techniques in laser medicine in the last two decades. In typical configurations, the optical unit of laser Doppler flowmeter for diagnostical applications can be considered as an optode with an open optical channel; this channel is traced through the probed tissue volume with expressed motions of the erythrocytes. In particular, such optode can be designed as a diode laser and a photodetector coupled with a pair of spatially separated light-delivering and light-collecting fibers. Coherent light travels through the delivering optical channel, reaches the probed tissue volume, is multiply scattered and, as a result, undergoes a Doppler frequency modulation due to the sequences of scattering by moving elements of the tissue structure such as erythrocytes. Part of the backward or forward frequency-modulated light is collected by the second optical fiber and, being observed in the detection plane, induces the random interference pattern, or dynamic speckle pattern, whose correlation or spectral properties depend on dynamic parameters of the ensemble of erythrocytes. Thus, evaluating the spectral moments of *temporal* speckle intensity fluctuations, one can determine the average velocity of erythrocyte motions through the micro-capillary network in the probed volume. Another approach is based on the statistical analysis of *spatial* fluctuations of speckle pattern images induced by scattered light and captured with the given exposure time. It can be shown, that for statistically homogeneous and ergodic spatial-temporal speckle intensity fluctuations the estimations of statistical moments will give equal results for spatial averaging of instantaneous values of speckle intensity across the pattern area and for temporal averaging of the time-dependent intensity fluctuations in the fixed detection point.

PHYSICAL BACKGROUND

If a multiply scattering non-stationary *homogeneous* medium is probed using full-field speckle technique (such as, e.g., LASCA method), then temporal fluctuations of backscattered light amplitude in an arbitrary point of the object plane (which usually coincides with interface) can be characterized by the field correlation function $G(\tau)$. In the case of probe light propagation in a *heterogeneous* scattering medium, temporal correlation function of speckle intensity fluctuations in the detection point can be obtained by summation over the parts of effective optical paths, which are associated with

propagation of each partial component of scattered optical field in regions with differing optical or dynamic properties. Fig. 1 illustrates the effect of underlying "dynamic" layer in the case of probing of two-layered scattering medium on the correlation decay with an increase of the source-detector separation. When the "banana-shaped" region, in which the partial components of scattered optical field are localized, penetrates into the modulating layer with expressed dynamics, it causes the fast decorrelation of the detected light fluctuations. In the case of weak absorption limit the mean value of penetration depth of a probe light can be estimated as z = 2d/4, where d is the source-detector separation.

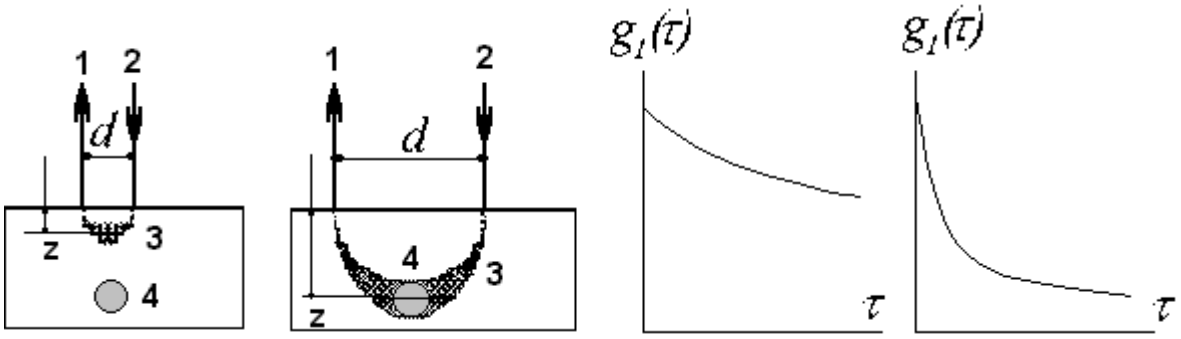


Figure 1. Location of the dynamic heterogeneity using measurements of the correlation decay of speckle amplitude fluctuations: 1 - light-collecting fiber; 2 - light-delivering fiber; 3-"banana-shaped" region; 4 - dynamic heterogeneity, $g(\tau)$ is the normalized temporal correlation function of the amplitude fluctuations.
The information about dynamic properties of underlying "modulating" layer can be obtained using analysis of radial distribution of the speckle contrast V(R,T) for the time-integrated image of the probed object surface in the dependence on exposure time T.

EXPERIMENTAL TECHNIQUE AND RESULTS

Statistical properties of time-integrated speckle patterns obtained in the accordance with Fig.1 for *in-vivo* tissues and phantom scatterers were studied using the setup that is schematically shown in Fig. 2.

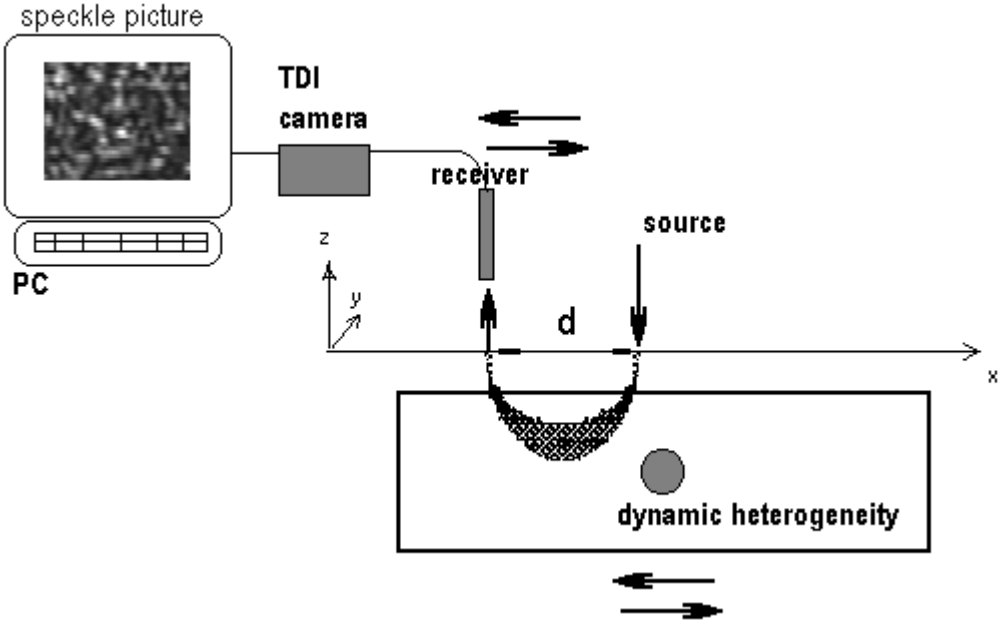
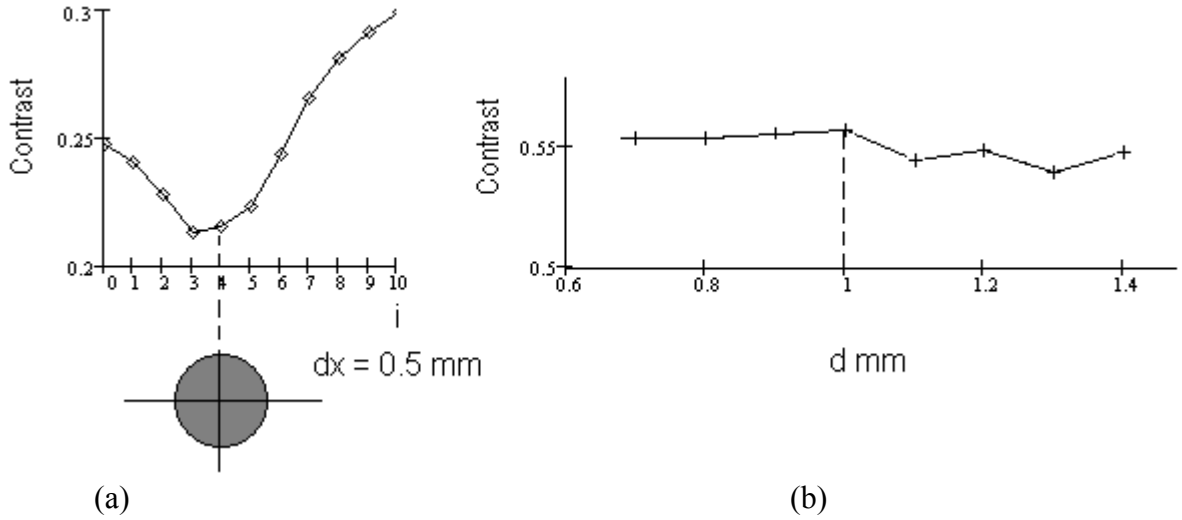


Figure 2**.** The experimental setup for recording time-integrated speckle patterns: localized light source (focused laser beam), receiver (optical fiber), Teflon plate with cylindrical channel filled by strongly scattering liquids.

Focused beam of He-Ne laser was used as a localized light source. Diameter value of the diameter of laser beam on the object surface was of 100 μm. Outgoing light from localized region of the object surface was collected by multimode fiber. EDC-1000L monochrome CCD camera (manufacturer is Electrim Corp., USA) was used to capture dynamic speckle patterns from the fiber output with given value of exposure time. Teflon plate with cylindrical channel filled by strongly scattering liquids (e.g. milk solution) was used as the phantom object. Experiments were provided with phantoms as well as in vivo-human tissues (such as human skin).



(a) (b)

Figure 3. Localization of the dynamic heterogeneity: a) Contrast as a function of the dynamic heterogeneity displacement in transverse direction; b) Contrast as a function of the source-detector separation d mm as related with the mean value of penetration depth of a probe light.

Value of residual contrast for given exposure time is determined by the relative fractions of Doppler-shifted and non-shifted components of backward scattered light and correspondingly, by the localization and scattering of stationary and moving scatterers (milk particles) in the probed volume. Thus, the dependence of residual contrast on exposure time can be used for reconstruction of the depth distribution and localization of the dynamic heterogeneity (erythrocytes).

CONCLUSIONS

Modified LASCA technique based on the application of localized light source in combination with the speckle contrast analysis of time-integrated dynamic speckle patterns can be used for analysis of axial distributions of blood microcirculation parameters. One of the simplest approaches to depth distribution analysis of the blood microcirculation parameters is based on estimations of the contrast of speckle patterns recorded with given exposure times in the dependence on localization of the dynamic heterogeneity. Further development of this technique should be directed on the improvement of its spatial resolution.