Measuring the dynamics of scattering centres in the ocular fundus during laser heating

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The study is focused on the analysis of the diffusing-wave-spectroscopy signal recorded in-vivo on the ocular fundus. The proposed instrumentation is based on a modified commercial ophthalmic microscope equipped with a therapic laser and an He-Ne laser. Temporal fluctuations of the back-scattered He-Ne signal revels motion of molecules and thus changes in retinal temperature and choroidal flow.

1 Introduction

This activity is focused on ocular fundus examination using an optical technique known as Diffusion Wave Spectroscopy (DWS) [1, 2]. We propose a non-invasive instrument based on DWS able to analyze scatterers-mobility variations in the fundus tissues. This information could be extremely useful to determine the end-point in the Transpupillary Thermo Therapy (TTT) treatment. TTT is known to be an effective treatment for several ocular diseases [3, 4, 5]. However, up to now, few studies have been carried out in order to determine a measurable end-point for the treatment, thus leading to several under or over exposure. Due to the intra- and inter-subject variability of the retinal pigmentation and choroidal perfusion, this parameter is not easily predictable, thus making it impossible to perform a feed-forward control in terms of “optimal dose”. Since under and over exposure produces ineffective treatment or local blinding respectively, this constitutes a substantial limitation in TTT diffusion.
Nevertheless, motion of the ocular-fundus scattering centres is mainly thermally induced or due to blood flow. Hence, our instrument could represent a real innovation in the use of TTT.

2 Basic Theory and System Description

Diffusing-wave-spectroscopy (DWS) is a technique able to monitor microscopic movements in turbid media [1, 2, 6]. The most fascinating feature of this technique is the ability to resolve the molecules motion, e.g. thermal motion and blood flow, in static matrix of tissue. Diffusing-wave-spectroscopy (DWS) properly applied could allow the analysis of ocular fundus tissues [7].
Ocular fundus layers could be thought as a multilayer media with a random flow localized in the choroids. Photons propagation in a similar medium has been investigated by different researchers [1, 2]. Considering the two-cells setup experiment proposed by Scheffold et al. [2], we can develop a simple interpretation of the resulting correlation function in terms of contributions of the individual layers: qualitatively we can associate the long-delay time information with the short trajectories of photons because photons with long trajectories are statistically completely decorrelated at long delay times, thus their contribution to the field autocorrelation function is not significant. Photons with short trajectories consist of the few photons travelling into the retinal layer without reaching the choroidal capillaries. As discussed in our previous work, the injected photons display a sort of ballistic motion [7], thus the number of photons reaching the sclera is dominant. Thus, we developed a simple model for these ballistic photons to relate the scatterers mean square displacement to the electric field autocorrelation function $g_1(\tau)$. Afterwards we extended this result to all the propagating photons. In order to investigate the ocular fundus, we developed the system shown in Fig. 1. We modified a commercial ophthalmic microscope (BQ900, Haag-Streit AG, Switzerland) equipped with a standard therapeutic laser diode TL ($\lambda = 810$ nm, Quantel Medical IRIDIS, France). Since the TL coherence length was found inadequate, a He-Ne laser was exploited as probe beam source. A 70/30 beam splitter BS was used to couple probe beam and to collect the scattered light according to Fig. 1. The scattered light was then guided by the single mode fiber to a single photon counting module (SPCM-AQR-14-FC, Perkin-Elmer, Québec, Canada). To select only the He-Ne scattered light, an interference filter was fixed in front of the collection lens L_1.
The electric signal from the single photon counting module (SPCM) was processed by the digital correlator DC (FLEX99S160B, Correlator.com, USA).

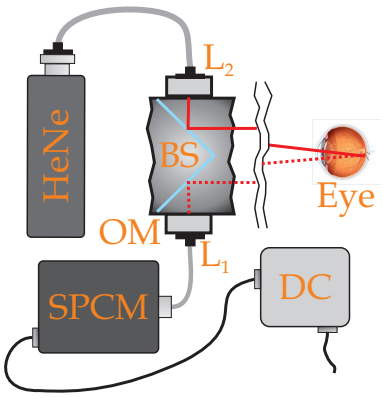

Fig. 1 *Block diagram of the system. HeNe: He-Ne Laser; OM: section of the Ophthalmic Microscope; BS: Beam Splitter; L_1 and L_2: fiber coupling lenses; SPCM: Single Photon Counting Module; DC: Digital Correlator.*

3 Results and Discussion

First in-vivo measurements were performed to study the effects of a moderate temperature increase of the ocular fundus. As an animal model we used a pigmented rabbit; its ocular fundus was irradiated by TL with a power set to 200 mW and spot diameter of 4.1 mm. Immediately before TTT, an autocorrelation function was acquired in 5 s. Afterwards, we started the laser thermal treatment. During the 60 s NIR laser exposure, an autocorrelation function was acquired each 10 s for a total of 6 readings. After the TTT, an additional autocorrelation function was acquired in 5 s. To exclude possible visible alterations of the tissues at the end of the treatment, an ophthalmologist observed the eye fundus. As an example, Fig. 2 shows the normalized electric field autocorrelation functions $g_1(\tau)$ obtained before, after 30 s and at the end of the laser thermal treatment. The corresponding dimensionless mean-squared displacements $\rho(\tau)$ of the scattering sites calculated according to our model [7] are reported in Fig. 3.

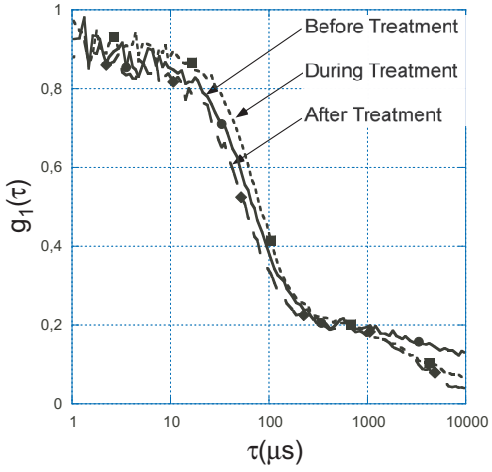

Fig. 2 *Electric field autocorrelation functions.*

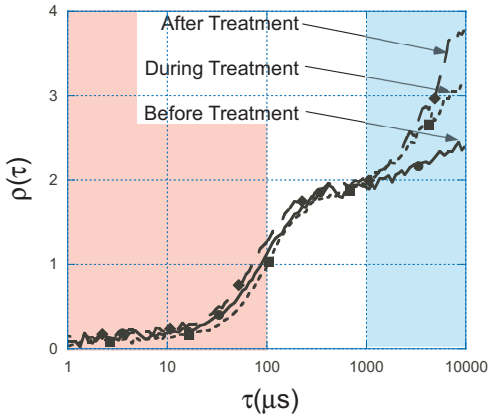

Fig. 3 *Dimensionless mean-squared displacements $\rho(\tau)$ calculated from the $g_1(\tau)$.*

As expected, the retinal tissues heating mainly affects the long-delay time region. As clearly shown in Fig. 2 and 3, the developed system is able to detect such a variation, thus potentially providing an endpoint for the TTT treatment.

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