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Performance analysis of classical, model-based and eigenvector methods: Ophthalmic arterial disorders detection case

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Abstract

In this study, ophthalmic arterial Doppler signals recorded from 214 subjects were processed using classical, model-based, and eigenvector methods. The classical method (fast Fourier transform), two model-based methods (Burg autoregressive, least squares modified Yule–Walker autoregressive moving average methods), and three eigenvector methods (Pisarenko, multiple signal classification, and Minimum-Norm methods) were selected for performing spectral analysis of the ophthalmic arterial Doppler signals. Doppler power spectral density estimates of the ophthalmic arterial Doppler signals were obtained using these spectrum analysis techniques. The variations in the shape of the Doppler power spectra were examined in order to detect variabilities such as stenosis, ocular Behcet disease, and uveitis disease in the physical state of ophthalmic arterial Doppler signals. These power spectra were then used to compare the applied methods in terms of their frequency resolution and the effects in detecting stenosis, Behcet disease and uveitis disease in ophthalmic arteries.

Keywords: Doppler signal; Spectral analysis; Power spectral density; Ophthalmic arterial disorders

1. Introduction

Doppler ultrasound is widely used as a noninvasive method for the assessment of blood flow, both in the central and peripheral circulation [1,2]. It may be used to estimate blood flow, to image regions of blood flow and to locate sites of arterial disease as well as flow characteristics and resistance of ophthalmic arteries [3–6]. Doppler devices work by detecting the change in frequency of a beam of ultrasound that is scattered from targets that are moving with respect to the ultrasound transducer. The Doppler shift frequency f_D is proportional to the speed of the moving targets:

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$$f_{\mathrm{D}} = \frac{2vf\cos\theta}{c}, \tag{1}$$

where v is the magnitude of the velocity of target, f is the frequency of transmitted ultrasound, c is the magnitude of the velocity of ultrasound in blood, and θ is the angle between ultrasonic beam and direction of motion. Since the scatterers within the ultrasound beam usually do not move at the same speed, a spectrum of Doppler frequencies is observed [1–6].

The Doppler power spectrum has a shape similar to the histogram of the blood velocities within the sample volume and thus spectral analysis of the Doppler signal produces information concerning the velocity distribution in the artery [1–8]. The estimation of the power spectral density (PSD) of the Doppler signal is performed by applying spectral analysis methods. By monitoring the Doppler power spectrum, variation of the spectral properties of the Doppler signal and a number of extents related to the blood flow can be tracked. A number of spectral estimation techniques have recently been developed and have been compared to the more standard fast Fourier transform (FFT) method, or Welch method, for Doppler ultrasonic signal processing [3,4,7,8]. FFT-based power spectrum estimation methods are known as classical methods and have been widely studied in the literature [9,10]. Autoregressive (AR) and autoregressive moving average (ARMA) methods are model-based (parametric) methods. AR spectra can be computed by different algorithms such as the Burg method. ARMA spectra can be computed via several algorithms such as the least squares modified Yule–Walker method [9,10]. Eigenvector methods are used for estimating frequencies and powers of signals from noise-corrupted measurements. Pisarenko [11], multiple signal classification (MUSIC) [12], and Minimum-Norm [13] methods are eigenvector methods which can be used for obtaining PSD estimates of Doppler ultrasonic signals [8,14–17]. Up to now, there is no detailed comparative study in the literature relating to the assessment of spectral estimation methods in detecting variabilities such as stenosis, Behcet disease and uveitis disease in ophthalmic arteries.

Doppler ultrasonography is a reliable technique, which demonstrates the flow characteristics and resistance of ophthalmic arteries in various ocular and orbital disorders such as stenosis, Behcet disease, and uveitis disease [3–6]. Behcet disease is a chronic, recurrent and multisystem inflammatory disorder characterized by orogenital ulcers, ocular and skin lesions. Ocular involvement is the most frequent serious complication of Behcet disease and therefore, blood flow velocity changes of ophthalmic arteries are defined as the most evident symptoms of Behcet disease [18–20]. Uveitis means "inflammation of the uvea", or the middle layer of the eye. The uvea consists of three structures: the iris, the ciliary body, and the choroid [21,22]. Since ophthalmic artery stenosis, ocular Behcet disease, and uveitis disease cause serious visual loss and result in blindness within a few years, early detection of changes in ophthalmic artery is important for prevention of blindness.

In this study, Doppler signals obtained from 214 subjects, 52 of them suffered from ophthalmic artery stenosis, 54 of them suffered from ocular Behcet disease, 45 of them suffered from uveitis disease and the rest of them were healthy subjects (control group) who had no ocular or systemic disease. The ophthalmic arterial Doppler signals were then examined by taking into consideration of their PSDs. The FFT, Burg AR, least squares modified Yule–Walker ARMA, Pisarenko, MUSIC, and Minimum-Norm methods were used for performing spectrum analysis of the ophthalmic arterial Doppler signals. Using these spectrum analysis techniques, PSD estimates and detailed documentations of the ophthalmic arterial Doppler signals were obtained. These methods were compared in terms of their frequency resolution and the effects in detecting stenosis, Behcet disease and uveitis disease in ophthalmic arteries.

2. Materials and method

2.1. Measurement of ophthalmic arterial doppler signals

Ophthalmic artery examinations were performed with a Doppler unit using a 10 MHz ultrasonic transducer. The block diagram of the measurement system is shown in Fig. 1. The system consisted of five units. These were 10 MHz ultrasonic transducer, analog Doppler unit (Diasonics Synergy), recorder (Sony), analog/digital interface board (Sound Blaster Pro-16 bit), and a personal computer with a printer. The ultrasonic transducer was applied on a horizontal plane to the closed eyelids using sterile methylcellulose as a coupling