Biocybernetics and Biomedical Engineering
2011, Volume 31, Number 1, pp. 17–25

Application of Coherence Function for Calculating Time Shifts between Axial Corneal Displacements and Electrical Heart Activity

MONIKA DANIELEWSKA*, MAŁGORZATA KOWALSKA, HENRYK KASPRZAK

Institute of Physics, Wrocław University of Technology, Wrocław, Poland

The heart activity is one of the most important factors influencing the ocular pulsation. It is known that the high correlation between axial corneal displacements and cardiovascular system activity exists. However, phase relationships between those factors are still unknown. The main goal of the research was to measure noninvasively longitudinal corneal apex displacement (LCAD) of the left eye, applying an ultrasonic sensor. Synchronically, the electrical heart activity (ECG) was recorded in Einthoven's triangle. To find phase dependencies between these signals the coherence function was used. It is observed that coherence value, computed between the first five harmonics of both signals, is different for shifted signals along each other. Therefore, the time delay between the ECG and LCAD signals, for which particular harmonic achieves the maximum of coherence function, was examined. It can be noticed that for increasing number of the signals' harmonic, the time delay between considered signals decreases. This tendency is clear for both of examined subjects. To receive more information about this phenomenon more subjects should be measured and the statistical test should be introduced to calculate the time delay values. The presented noninvasive method might be helpful in the future for measuring the IOP pulse and estimating hemodynamic status of the eye.

K e y w o r d s: longitudinal corneal apex displacement, ECG signal, coherence analysis, time shifts calculation

1. Introduction

With every heartbeat the blood is pumped into the eye globe causing changes of its volume [1] and IOP pressure. Pulsatile IOP variations are linked to radial displacements of the corneal surface [2]. This phenomenon is known as ocular pulse, which

* Correspondence to: Monika Danielewska, Institute of Physics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370, Poland, e-mail: monika.danielewska@pwr.wroc.pl
Received 27 April 2010; accepted 08 September 2010

is influenced by many factors, such as ocular blood flow [3], heart rate [4, 5], IOP propagation [6] or biomechanical properties of cornea.

So far many invasive [5, 7, 8] and noninvasive methods of ocular pulse measurements [1, 2, 9–11] were used. Application of high speed videokeratoscopy [12] showed that slow changes in corneal shape exist and some individual features of signals registered for different subjects can appear.

More accurate results of axial corneal displacements were received using ultrasonic technique [13, 14]. Average amplitude of longitudinal corneal displacements obtained in this way was around 20 μm. Additionally, numerical analysis using coherence function showed a close relationship between longitudinal corneal displacements and heart activity at particular frequency components [12, 14, 15]. Spectral analysis of the ocular pulse was examined by Evans using tonometry method [16]. He noticed that power of analyzed harmonics, related to the heart beat, is lower for glaucoma patients, compared with normal subjects.

Up to now some spectral and coherence analyses concerning the radial corneal displacement and the cardiovascular system activity have been carried out, but without any information about the phase relationships between these signals. The coherence function was used previously to investigate ocular mechanism [17], relationship between the pulse and miniature eye movements [18], accommodation [19] as well as thermoregulation [20]. It was also applied in researches concerning cardiac rhythms [21, 22] and cardiac arrhythmias [23].

Phase investigations are very interesting, because they can help to explain a process of IOP propagation, as well as blood propagation on the way from the heart to the eye globe. The accurate values of phase shifts between the ocular surface normal displacements and the blood pulsation are still unknown. Therefore, it was our inspiration to further studies.

The aim of this work was examination a phase relationship between the noninvasively, synchronically recorded longitudinal corneal apex displacements (LCAD) and the electrical heart activity (ECG) using the coherence function. The obtained information about the eye-heart phase relationships might be useful in the future to diagnose hemodynamic status of the eye globe and can help to predict ocular vascular diseases.

2. Materials and Methods

An ultrasonic distance sensor working at a frequency of 0.8 MHz was applied to measure noninvasively longitudinal corneal apex displacement (LCAD) of the left eye with accuracy below 2 μm. The same method was used in the study of binocular corneal pulsations [14]. Distance between the transducer's head and the corneal surface was around 15 mm. The diameter of the ultrasonic beam focused on the cornea was around 1 mm.