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Surface electromyography analysis of blepharoptosis correction by transconjunctival incisions

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ABSTRACT

Upper eyelid movement depends on the antagonistic actions of orbicularis oculi muscle and levator aponeurosis. Blepharoptosis is an abnormal drooping of upper eyelid margin with the eye in primary position of gaze. Transconjunctival incisions for upper eyelid ptosis correction have been a well-developed technique. Conventional prognosis however depends on clinical observations and lacks of quantitatively analysis for the eyelid muscle controlling. This study examines the possibility of using the assessments of temporal correlation in surface electromyography (SEMG) as a quantitative description for the change of muscle controlling after operation. Eyelid SEMG was measured from patients with blepharoptosis preoperatively and postoperatively, as well as, for comparative study, from young and aged normal subjects. The data were analyzed using the detrended fluctuation analysis method. The results show that the temporal correlation of the SEMG signals can be characterized by two indices associated with the correlation properties in short and long time scales demarcated at 3 ms, corresponding to the time scale of neural response. Aging causes degradation of the correlation properties at both time scales, and patient group likely possess more serious correlation degradation in long-time regime which was improved moderately by the ptosis corrections. We propose that the temporal correlation in SEMG signals may be regarded as an indicator for evaluating the performance of eyelid muscle controlling in postoperative recovery.

1. Introduction

Blepharoptosis or ptosis, which is a congenital, acquired, or age-related drooping of the upper eyelid, results from dysfunction of the levator aponeurosis. For healthy individuals, the upper eyelid covers around 1.0–1.5 mm of the superior part of the cornea when the eye is open. For patients with blepharoptosis, the amount of cornea covered by the upper eyelid varies, resulting in visual disturbances and cosmetic problems. Surgery to correct the ptosis, which is one of the most common facial rejuvenation procedures (Sakol et al., 1999), is the most effective treatment for blepharoptosis (Lai et al., 2013; Smith et al., 1969).

Transcutaneous (Waqar et al., 2010) and transconjunctival (Patel and Malhotra, 2009) incisions are two methods that are used in blepharoptosis correction surgeries. The main difference between the two methods is that the orbicularis muscle is disrupted with the transcutaneous incision. The basic concept of the correction is to strengthen the levator aponeurosis by shortening Müller's muscle and advancing and fixing the levator aponeurosis to the tarsal plate (Ichinose and Leibovitch, 2010; Patel et al., 2010). Normally, the closure and elevation of the upper eyelid automatically maintains the balance. However, if the levator aponeurosis is strengthened by shortening it with the transcutaneous procedure, the orbicularis is weakened, and the balance is

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disrupted, which may result in lagophthalmos. In contrast, if the levator aponeurosis is strengthened with the transconjunctival procedure, the orbicularis muscle is kept intact and unaltered. Hence, the transconjunctival approach has the advantages of shorter recovery time, less postoperative swelling, and nearly no or faster-recovering lagophthalmos immediately after the surgery (Ichinose and Tahara, 2007). Because we were familiar with ptosis correcting surgeries that involve the transconjunctival approach, this study was conducted with the transconjunctival approach.

Although surgical corrections of upper eyelid ptosis have been common and effective since 1806 (Beard, 1986; Servat and Mantilla, 1986), the prognoses of the patients generally rely upon clinical observations and lack definite and quantitative preoperative and postoperative descriptions of the eyelid muscles and their postoperative recoveries. The electrooculography (EOG) is used in recording of eye movements, which involve most of the muscles around the eyeball (Fuchs and Luschei, 1970). It is not designated for specified muscles related to eyelid closure and opening. For the evaluation of blepharoptosis correction that involves the orbicularis oculi muscle and the levator aponeurosis with the Muller's muscle, it is ideal to use surface electromyography (SEMG) (Ban et al., 2010; Gorkovenko et al., 2012) rather than EOG. Therefore, we performed a SEMG data analysis of upper eyelid ptosis corrections that involved transconjunctival incisions in order to objectively and quantitatively assess the improvements in eyelid muscle control. Eyelid SEMG signals are recordings of the electrical signals on the eyelid surface that measure the activities of Müller's and the orbicularis muscles. These signals result from the many action potentials that are involved in muscle force generation. The electrical activity of a muscle starts before the generation of force occurs and can be detected by SEMG recordings before the onset of the movement (Evinger et al., 1991; Holobar et al., 2014; Yun et al., 2014). Because the frequency distribution of the eyelid SEMG signals are not as simple as a special class of noise like $1/f$ (see Section 3), a time series analysis approach beyond a Fourier spectrum analysis was needed for this study. Based on the assumption that effective and efficient muscle control of eyelid closure and opening involves specific intrinsic properties in the SEMG signals, muscle functionality was evaluated in this study by analyzing the temporal correlations in the recorded time series with the detrended fluctuation analysis (DFA) (Peng et al., 1994).

DFA is a method that was developed for analyzing complex time series data and that is especially useful for data representing the dynamics of complex systems. Biomedical systems are complex dynamical systems that consist of a group of constituents (subsystems) that usually interact among one another through feedback. The DFA method detects intrinsic correlations in a signal by measuring the fluctuations of the signals with respect to local trends in a scale window. Because this method is free of models and easy to implement, it has been successfully applied to data analysis in a wide variety of problems in physical, engineering, medical, and social sciences and has specifically examined a number of biomedical signals, such as heartbeats (Peng et al., 1995) and sleep electroencephalography (D'Rozario et al., 2013); biological data, such as DNA sequences (Peng et al., 1994); and financial data, such as stock market indices (Wu, 2012). Thus, the use of DFA was suitable to examine our hypothesis that young and aged normal subjects and patients have distinct temporal correlations in their eyelid SEMG recordings.

2. Patients and methods

This study, which was a retrospective study that was based on clinical data on upper eyelid ptosis corrections, was approved by the Mackey Memorial Hospital Institutional Review Board (IRB No. 13MMHIS262).

2.1. Test protocols

The SEMG examination was standardized and performed by one technician. The procedure was explained to the subjects before the test started. The patients were selected as candidates for the SEMG examination before the surgery if they did not have the following conditions: previous eyelid surgery, myasthenia gravis, HIV (+), pregnancy, or age less than 18 years. A patient with blepharoptosis was examined if 2–5 mm of his/her upper limbus was covered by the lid margin. A normal subject had less than 1.5 mm of his/her limbus covered by the lid margin. The SEMG measurements were actively recorded by two channels with two electrode tapes (0.5 cm × 0.5 cm) that were placed beneath the surfaces of each subject's left and right lateral eyebrows (Bailey et al., 2009; Schumann et al., 2010; Tassinary and Cacioppo, 2000), two electrode tapes that were placed on the ipsilateral cheek for reference recording, and one electrode tape that was placed on the chin as a ground (see Fig. 1). The cables were immobilized with tape. The subjects lay in a supine position during the SEMG. Test signals were collected by the technician to confirm that the electrodes were adhered correctly, and then the examination was performed normally. Next, each subject was asked to close his/her eyelids three times for 15 s each and then open his/her eyelids three times for 15 s each while gazing frontally. The same procedures were applied to all of the subjects.

2.2. Subjects

Thirteen patients who underwent surgery for blepharoplasty between November 2011 and December 2014 were involved in the study. Four of the 13 patients agreed to be in the study, while the other nine patients did not desire to undergo the examinations or the rehabilitation facility was not available during those periods. Eyelid SEMG (Fig. 1) recordings were performed with the eyes open and closed in the four patients with blepharoptosis and in six young and six aged normal subjects without ptosis. A transconjunctival

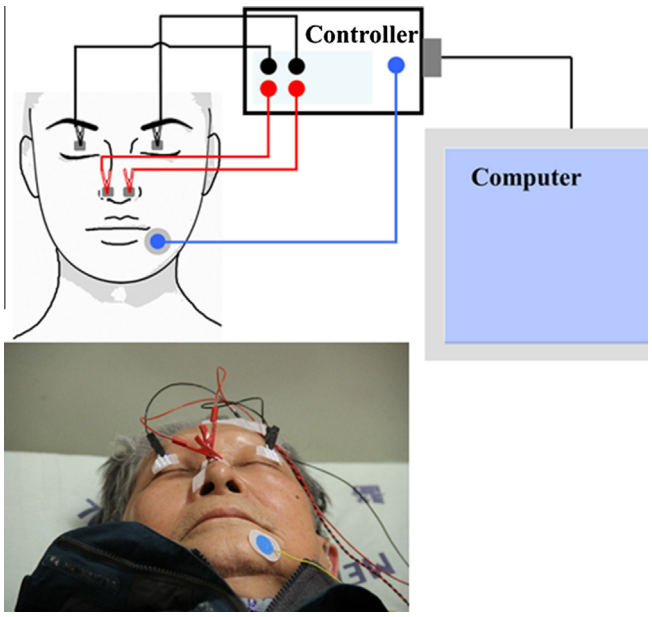

Fig. 1. Experimental setup for the eyelid surface electromyography (SEMG) recordings. Black: point of active recording. Red: point of reference recording. Blue: point of ground. The recording was implemented with an EMG recorder with a sampling frequency of 31.95 kHz for two channels with 16-bit precision and noise level <6 μV. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)