Contralateral EMG-Triggered Electrical Stimulation of the Eyelid

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Abstract

Electrical stimulation has been shown to activate the denervated orbicularis oculi, restoring eyelid movement following 7th nerve paralysis. Relatively high currents and long pulse widths are necessary, however, to achieve maximum closure. In order to prevent the unwanted activation of nearby sensory neurons due to excessive current spread, several options for lowering stimulation thresholds and minimizing the current necessary to achieve functional closure are being investigated. These include the use of multiple stimulation channels, promotion of reinnervation, and triggered stimulation to provide a synchronous blink with the contralateral side. This study validated the design of a system that uses EMG activity recorded from the healthy contralateral side in a unilateral model of 7th nerve paralysis as a means of triggering the delivery of stimulation pulses to the paralyzed orbicularis oculi.

1. INTRODUCTION

Dysfunction of the 7th cranial nerve due to damage or disease leads to facial paralysis and the loss of the ability to blink the eye [1]. This in turn can lead to corneal damage, infection, perforation, and potential loss of the eye. Current methods for treatment include the implantation of gold weights or mechanical springs in the eyelid, the use of artificial tears, nerve and muscle transfer, and tarsorrhaphy [2]. While all of these techniques are helpful in preserving the eye, none of them, even when used in combination, are fully effective. Additionally, they are often inconvenient, subject the patient to multiple surgical procedures, and are cosmetically unacceptable. Electrical stimulation of the orbicularis oculi muscle has the potential to provide a more elegant and effective method for eliciting eyelid closure, provided it can achieve this without causing adverse reactions such as the unwanted stimulation of nearby sensory neurons.

We have quantitatively studied the effects of acute electrical stimulation of the orbicularis oculi in rabbit [3]. The results of this study indicate that the pulse requirements for eliciting closure with bipolar, biphasic stimuli are close to threshold values for eliciting movement in adjacent muscles in anesthetized animals and for eliciting a conscious reaction in awake animals. This seems to indicate that strategies for decreasing the current requirements for stimulating closure may be important for providing an acceptable eye blink without generating adverse reactions. Three possible strategies are being explored for reducing the stimulating current requirements. These include the use of multiple stimulation channels [4], promotion of reinnervation in the paralyzed muscle [3], and the use of triggered stimulation to provide a synchronous blink with the contralateral side. We have chosen to focus on triggered stimulation for this study.

The levator palpebrae muscle, which contracts tonically to maintain opening of the palpebral fissure and relaxes during normal eye closure, is innervated by the 3rd cranial nerve and therefore unaffected by 7th nerve lesion. The majority of patients who suffer from 7th nerve paralysis are affected unilaterally [5], however the levator palpebrae acts bilaterally, and therefore relaxes on both sides when the healthy eyelid blinks. By monitoring closure of the healthy eyelid it is possible to trigger a stimulation pulse to activate the orbicularis oculi on the paralyzed side at a time when the antagonistic levator palpebrae is relaxed [6], possibly decreasing the amount of force that must be generated to close the eyelid and therefore decreasing stimulation requirements. In addition, the kinematics of the stimulated eyelid closure should be similar enough to a normal blink to provide cosmetically desirable, natural-looking symmetry [7].
This study focused on the design of a system that uses electromyographical (EMG) activity from a healthy eyelid as a signal for triggering the delivery of stimulation pulses to the paralyzed orbicularis oculi on the contralateral side.

2. METHODS

A data acquisition system was programmed to record and process EMG activity such that its onset could be detected and used as a trigger for the delivery of stimulation pulses. The system was tested using a single rabbit with surgically induced unilateral orbicularis oculi paralysis. EMG was recorded from the healthy eyelid of the rabbit and used to trigger a stimulation pulse that was delivered to the paralyzed eyelid through an implanted electrode.

2.1. Data Acquisition and Triggering

A software program was written in LabVIEW (National Instruments) that records voltages from an analog input, rectifies the incoming signal, and integrates it over a period of time. The average input voltage over the integration period is compared to a threshold value. When the threshold value is surpassed, a voltage stimulus is delivered to a pulse isolator unit (A-M Systems, model 2200), which converts it to an isolated current stimulus. The input sampling rate, integration period, threshold magnitude, and stimulus parameters are programmed as operator-defined values.

2.2. Experimental Validation

The orbicularis oculi muscle of a single rabbit was paralyzed unilaterally by sectioning the 7th cranial nerve. Immediately after the nerve was divided, an electrode (Ad-Tech, Spencer Probe) was inserted into the subcutaneous plane near the margin of the upper eyelid. A curvilinear incision was made extending from the insertion site to the top of the skull, between the ears, and blunt dissection was used to create a subcutaneous path from the posterior lip of the scalp incision to the middle of the back between the shoulder blades. A small incision was made in the center of the back and the electrode was threaded through the subcutaneous pocket, exiting near the center of the back. The remainder of the electrode was coiled externally into a protective spool that was sutured to the back of the rabbit and was covered by a ¾-length rabbit jacket (Harvard Apparatus).

One week following the induction of paralysis and electrode insertion, the rabbit was anesthetized and placed in a restraint (Harvard Apparatus, Bunny Snuggle). Two fine-wire EMG electrodes were inserted into the functioning orbicularis oculi muscle on the side contralateral to the initial surgery, with inter-electrode spacing of approximately 1cm. A 25-gauge needle was inserted subcutaneously into the back of the rabbit and used as a ground contact. The EMG electrodes were connected to a differential pre-amplifier (Grass, model P55) with the gain and bandwidth set to 10,000 and 10Hz–10kHz, respectively.

After the rabbit recovered from anesthesia, the cornea on the side of the healthy eyelid was lightly touched with a cotton swab in order to stimulate eyelid closure and generate EMG, which was recorded by the previously described LabVIEW program. The sampling rate was set to 10kHz, the integration time was set to values ranging from 1 to 10ms and the threshold value was manually adjusted until the recorded EMG consistently produced a triggered output pulse during closure but not during periods of inactivity. The output of the pulse isolator unit was connected to 2 of the contacts on the stimulating electrode and the paralyzed eyelid was visually monitored to assess response to the EMG-triggered stimulation pulses. The output of the pre-amplifier (EMG activity), the voltage pulses generated by the LabVIEW program, and the voltage across a sense resistor placed in series with the stimulating electrode were monitored on an oscilloscope (Tektronix, TDS 2024).

3. RESULTS

The system was able to consistently deliver stimulation pulses to the paralyzed eyelid that were triggered by the onset of EMG activity recorded from the healthy eyelid. This was verified by visual identification of movement of the paralyzed eyelid and voltage recordings on the oscilloscope (see Figure 1).

4. DISCUSSION AND CONCLUSIONS

There was a slight delay between the onset of the recorded EMG and the delivery of the stimulation pulse that was due largely to the programmed integration time. Some integration
is necessary to discriminate between actual EMG activity and possible noise, but the time allocated for this may be decrease as the system is optimized. The degree of delay in stimulation that can be tolerated is yet to be determined, but the current delay, which is approximately 10ms, is much shorter that the closing phase for a normal blink, which is approximately 80 to 100ms [8]. This seems to indicate not only that the levator palpebrae muscle should still be relaxed during activation due to such stimuli, but that cosmetic symmetry should not be severely affected either.

This experiment validated the use of the system described here for triggering stimulation of a paralyzed orbicularis oculi muscle based on EMG activity recorded from a healthy contralateral eyelid. The next step will be to integrate video capability so that a quantitative assessment of eyelid closure can be made both with and without contralateral EMG triggering. This will provide information regarding the actual benefits of triggered stimulation both in terms of its affect on the magnitude of eyelid closure due to a given stimulation pulse and the cosmetic effects of synchronous blinking.

References

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