

## Electrical Stimulation of the Paralyzed Orbicularis Oculi

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### Abstract

*Electrical stimulation of the orbicularis oculi muscle was performed at 1 and 4 weeks after induced paralysis of the 7th cranial nerve, as well as in normal rabbit. Strength-duration curves for muscle twitch demonstrated chronaxie values of  $0.439 \pm 0.023\text{ms}$  (mean  $\pm$  SD) in normal ( $N = 2$ ),  $56.4 \pm 7.5\text{ms}$  after one week of paralysis ( $N = 2$ ) and  $24.1 \pm 0.6\text{ms}$  after four weeks of paralysis ( $N = 2$ ). In addition, percent closure was measured for biphasic pulses ranging from 0.5ms to 100ms per phase and biphasic pulse trains ranging from 0.5ms to 10ms per phase delivered at 50Hz. Normal rabbit demonstrated the greatest degree of closure, followed by rabbits with 1 week of paralysis and 4 weeks of paralysis for nearly all sets of stimulation parameters. Both normal rabbit and rabbit with 1 week of paralysis achieved greater than 80% closure with a train of 5 consecutive 10ms pulses, while rabbit with 4 weeks of paralysis achieved a maximum of  $71.5 \pm 9.2\%$  closure for the same stimulation parameters.*

### 1. INTRODUCTION

Paralysis of the orbicularis oculi muscle results in incomplete eyelid closure during both voluntary and reflex movements [1]. Because eyelid closure is the means by which the cornea is lubricated, functional deficits in the ability to close the eyelid can lead to corneal damage and permanent vision impairment. Current methods for ensuring eye closure include gold weights attached to the eyelid, artificial tears, and tarsorrhaphy (suturing the eyelid closed) [2 - 4]. All of these methods help preserve the cornea; but they can limit vision, and they are often not fully effective, inconvenient and cosmetically unacceptable. Electrical stimulation of the orbicularis oculi muscle has the potential to provide a much more elegant and effective method for eliciting eyelid closure.

### 2. METHODS

The orbicularis oculi muscle was paralyzed in 4 rabbits by sectioning the 7<sup>th</sup> cranial nerve. Two rabbits were paralyzed for a total of 1 week, while the other 2 were paralyzed for a total of 4 weeks. In addition, 2 normal, non-paralyzed rabbits were used for comparison. At the end of this period, each rabbit was anesthetized and an electrode was inserted into the subcutaneous plane near the margin of the upper eyelid, such that metal contacts rested in the subcutaneous space near both the medial and lateral canthus. These contacts were used to deliver biphasic, current controlled stimulation pulses. A high speed digital video camera was used to record the response of the eyelid to stimulation, and image processing software was used to quantify lid closure.

#### 2.1. Dissection of 7<sup>th</sup> Cranial Nerve

The 7<sup>th</sup> nerve was identified and divided in rabbit resulting in paralysis of the orbicularis muscle. After the skin of the cheek was shaved, an approximately 1cm vertical incision was made through the skin, 1cm inferior to the center of a line drawn from the lateral canthus to the external auditory meatus and just anterior to the mandibular ramus. A combination of sharp and blunt dissection was used to divide the subcutaneous tissue and the parotid gland. The facial nerve trunk and its three large branches were identified on the surface of the masseter muscle. Stimulation of the nerve with a 0.5ms, 1mA biphasic current pulse produced simultaneous eye closure and ear movement. A 7mm section of the nerve and its branches were removed. Complete interruption was confirmed by stimulation of the proximal stump and observation of absent blink but maintained ear movement. Stimulation of the distal nerve resulted in only eye blink.

Persistence of paralysis was verified weekly and immediately prior to electrode insertion by lightly touching the cornea with the tip of a cotton swab and gauging the animal's response.

A healthy eyelid demonstrated complete closure of the palpebral fissure with no accompanying action by the nictitating membrane. A paralyzed eyelid demonstrated evidence of strain (slight shaking) by the animal in an attempt to close the palpebral fissure, resulting in narrowing but incomplete closure. In unanesthetized animals, this was accompanied by lateral movement of the nictitating membrane.

## 2.2. Electrode Placement

A small cutaneous stab incision was made using a #11 blade, approximately 5mm lateral to the lateral border of the upper eyelid. A 14 gauge angiocatheter was inserted through the stab incision and into the subcutaneous plane across the length of the eyelid, 2mm superior to the lower border of the eyelid. The stylet of the angiocatheter was removed, and a depth electrode (Ad-Tech, Spencer Probe) was threaded into the subcutaneous space, through the lumen of the angiocatheter. The angiocatheter was withdrawn leaving the electrode in the subcutaneous space of the eyelid. A 4-0 silk anchoring suture was used to secure the electrode to the skin of the rabbit, 2cm lateral to the entry site.

The probe was 1mm in diameter and contained six cylindrical platinum contacts, each 2.3mm long and spaced 5mm apart. Five contacts fit in the subcutaneous space of the upper eyelid. The first and fifth contacts were used for electrical stimulation, giving a dipole spacing of 2cm.

## 2.3. Electrical Stimulation Protocol

Biphasic square wave current pulses were delivered using an isolated pulse stimulator (A-M Systems, Model 2100). Twitch thresholds were found by increasing the pulse amplitude from zero until the first sign of movement was visible. This was done with biphasic pulses for pulse widths ranging from 0.5 to 100ms per phase. Next, single stimulation pulses with amplitudes of 5, 7 and 10mA were delivered over the same range of pulse widths. Finally, pulse trains consisting of 5 and 10 pulses with pulse widths of 0.5, 5 and 10ms were delivered at a rate of 50Hz.

## 2.4. Blink Recording and Data Analysis

A high speed video camera (Dalsa, 1M75-SA) was used to record the response of the eyelid to

stimulation. Video was captured and recorded at a rate of 190 frames/second with a resolution of 0.083mm (Figure 1). An interface was created using LabVIEW (National Instruments) to coordinate the video recording and delivery of stimulation pulses. Eyelid separation was measured with National Instruments, Vision Assistant software by tracing the outline of the palpebral fissure created by the margin of both eyelids and calculating the enclosed area. The minimum value for each recording was divided by the maximum value to determine peak percent closure.

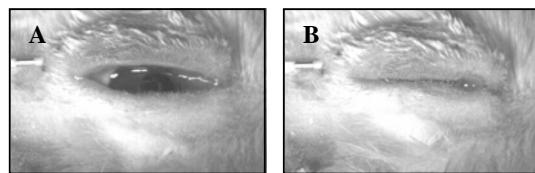


Figure 1 – Rabbit eyelid (1 week paralysis) with electrode inserted, A) without stimulation and B) during a train of 10ms, 5mA pulses.

## 3. RESULTS

Strength-duration curves for twitch threshold were generated (Figure 2) and the associated chronaxie and rheobase values compared (Table 1). Rheobase values were measured at 100ms pulse width and chronaxie values calculated using a least squares fit. The chronaxie value for normal orbicularis was within the expected range for motor nerve, while the chronaxie values for paralyzed orbicularis were within and slightly above the expected range for denervated skeletal muscle [5]. These were somewhat comparable to results reported for similar studies performed in dog [6].

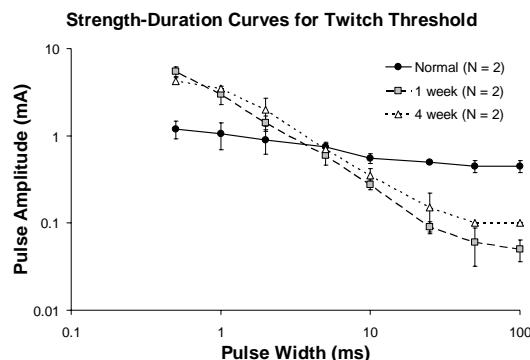
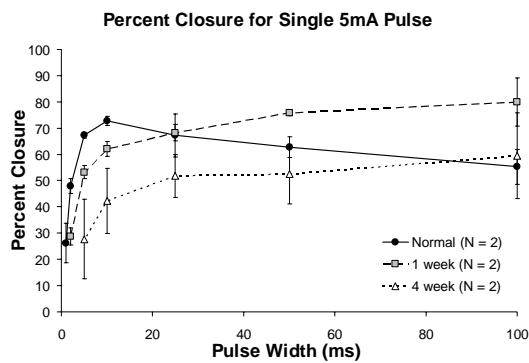


Figure 2 – Current threshold necessary to achieve muscle twitch, plotted as a function of pulse width.

*Table 1 – Chronaxie and rheobase values (measured at 100ms pulse width) for normal and denervated orbicularis oculi (mean  $\pm$  SD).*

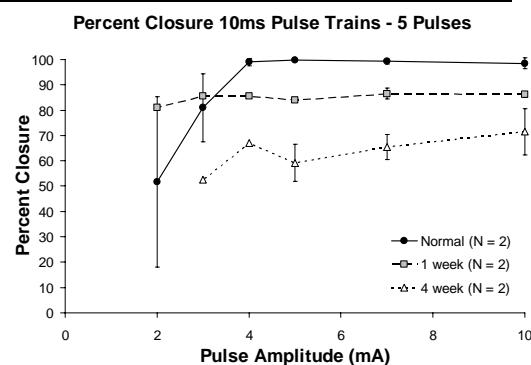
	Rheobase	Chronaxie
<b>Normal (N = 2)</b>	$0.45 \pm 0.07$ mA	$0.44 \pm 0.02$ ms
<b>1 week (N = 2)</b>	$0.05 \pm 0.01$ mA	$56.4 \pm 7.5$ ms
<b>4 weeks (N = 2)</b>	$0.10 \pm 0.00$ mA	$24.1 \pm 0.6$ ms

Complete eyelid closure could not be elicited using single biphasic pulses for the range of currents which the stimulator could provide ( $I \leq 10$ mA). Instead, percent closure was calculated for a range of pulse widths and amplitudes, and plotted as a function of pulse width with fixed amplitude (Figure 3). Percent closure increased rapidly with increasing pulse width between 0.5 and 10ms per phase. In this range, normal rabbit exhibited the greatest degree of closure, followed by those with 1 week of paralysis and 4 weeks of paralysis, respectively. At longer pulse widths, percent closure for each of the paralyzed rabbits slowly increased with pulse width, while normal declined due to loss of summing effects from the two phases, which tended to stimulate independently.



*Figure 3 – Percent eyelid closure achieved with a single 5mA biphasic pulse, plotted as a function of pulse width.*

Percent closure was also compared for trains of biphasic pulses delivered at 50Hz (Figure 4). Normal rabbit achieved the greatest degree of closure, followed by those with 1 week of paralysis and 4 weeks of paralysis, respectively. Both normal and 1 week paralysis rabbits achieved greater than 80% closure with trains of 5 consecutive stimulation pulses at 10ms per phase, while those with 4 weeks of paralysis achieved a maximum of  $71.5 \pm 9.2\%$  closure.



*Figure 4 – Percent eyelid closure achieved with 5 consecutive 10ms biphasic pulses delivered at 50Hz, plotted as a function of pulse amplitude.*

#### 4. DISCUSSION AND CONCLUSIONS

Electrical stimulation of the orbicularis oculi muscle achieved substantial closure (greater than 80%) in both normal rabbits and 1 week following induced paralysis of the 7<sup>th</sup> cranial nerve. Rabbits with 4 weeks of paralysis achieved partial closure (greater than 60%). These preliminary results indicate that electrical stimulation may have potential for restoring eye blink, however, more research is necessary to track changes over time and results of chronic stimulation, as well as to determine the degree of closure needed to maintain corneal health.

#### References

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