Origins of surface potentials evoked by electrical stimulation of oculomotor nerves: are they related to electrooculographic or electromyographic events?

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Intraoperative monitoring of oculomotor nerves is imperative for nerve preservation in patients undergoing skull base surgery, particularly surgery for lesions residing in the cavernous sinus or posterior fossa. This type of monitoring is often based on EMG responses of extraocular muscles, which produce graphic representations of potentials evoked by electrical stimulation of the nerves.5,8,13,14 This method is invasive, however, because it requires direct insertion of needle electrodes into the extraocular muscles or insertion of special ring electrodes into the orbit. Fukaya, et al.,3 reported that potentials recorded from surface electrodes are extremely similar to those of extraocular muscles, which are represented on electrooculograms, the authors investigated the true origin of these potentials.

Methods. Evoked potentials elicited by electrical stimulation of the canine oculomotor nerve were recorded from surface electrodes placed on the skin around the eyeball. A thread sutured to the center of the cornea was pulled and the potentials that were evoked during the resultant eye movement were recorded. These potentials were confirmed to originate in the eye and to be represented on electrooculograms because their waveforms were unaffected by the administration of muscle relaxant. To eliminate the influence of this source, the retina, a main origin of standing potentials of the eyeball, was removed. This resulted in the disappearance of electrooculography (EOG) waves elicited by eye movement. Surface potentials elicited by oculomotor nerve stimulation were the same before and after removal of the retina. Again the oculomotor nerve was electrically stimulated and electromyography (EMG) response of the extraocular muscles was recorded at the same time that potentials were recorded from the surface electrodes. In their peak latencies, amplitudes, and waveforms, the evoked potentials obtained from surface electrodes were almost identical to EMG responses of extraocular muscles.

Conclusions. Evoked potentials elicited by electrical stimulation of the oculomotor nerves and obtained from surface electrodes originated from EMG responses of extraocular muscles. These evoked potentials do not derive from the eye.

Key Words • intraoperative monitoring • oculomotor nerve • trochlear nerve • abducent nerve • evoked potential • dog

Abbreviations used in this paper: EMG = electromyography; EOG = electrooculography.
Materials and Methods

Animal Preparation

The experiments were performed using 30 adult mongrel dogs, each weighing between 8 and 12 kg. Our experimental protocols were approved by the Fukushima Medical University Institutional Animal Use and Care Committee. Efforts were made to minimize animal suffering and to reduce the number of animals used. Anesthesia was induced with an intravenous injection of 25 mg/kg of sodium pentobarbital and maintained by the administration of propofol (2 mg/kg/hr). After tracheal intubation, PaO₂ and PaCO₂ were maintained at 90 to 120 mm Hg and 35 to 45 mm Hg, respectively. Electrocardiography was used for continuous monitoring. A catheter was inserted into the femoral artery to measure blood pressure and to collect blood. Ringer lactate solution was infused through a peripheral vein (5–10 ml/kg/hr). Each animal’s body temperature (measured using a rectal probe) was maintained at 37 to 38°C with the aid of a heating blanket.

Each dog was placed in the prone position. A frontotemporal craniotomy was performed to expose the oculomotor, trochlear, and abducens nerves; two silver-ball electrodes were placed approximately 2 mm apart on each nerve and stimulated by bipolar electrical stimulation. The electrode proximal to the center was the cathode. These electrodes were connected to the isolator of an electrical stimulator, and square-wave stimulation was applied at 0.1 to 5 mA with a 0.1-msec duration. During stimulation, cerebrospinal fluid surrounding the stimulating electrodes was continuously aspirated to prevent spreading of the electrical current.

Recording of Surface Potentials

Potentials were recorded from surface electrodes placed on the skin around the eyeball. For Channel 1 (horizontal) recordings, active and reference electrodes were placed on the medial and lateral sides, respectively. For Channel 2 (vertical) recordings, active and reference electrodes were placed on the lower and upper parts of the eyeball, respectively. The surface electrodes were not special in any way and any ordinary electrode could have been used. Eye movement was observed without any optical instrument. Evoked potentials were examined with two types of bandpasses to evaluate movement; however, no eye movement was observed when the trochlear nerve was similarly stimulated. The waveforms were almost identical with or without eye movement. The latencies, amplitudes, and waveforms were almost the same for the two types of bandpasses. Sectioning of the oculomotor nerves resulted in the disappearance of all evoked potentials.

Effect of Removing the Retina

A thread sutured to the center of the cornea was manually pulled horizontally at 1 Hz, and potentials from the surface electrodes were recorded during eye movement. To confirm that these potentials originate in the eye, a muscle relaxant (vecuronium bromide, 0.2 mg/kg) was administered and the surface potentials were recorded again. To eliminate retinal influence the retina, a main origin of standing potentials of the eyeball, was removed. After incising the cornea, the content of the eyeball including the retina was removed, an acrylic ball was placed into the cavity, and the cornea was sutured. After removing the retina from the eyeball, surface potentials elicited by eye movement were recorded. Muscle relaxant was administered again to eliminate any effect of extraocular muscles. After the effect of the muscle relaxant had disappeared, surface potentials elicited by electrical stimulation of the nerves were recorded again.

Simultaneous Recording of Surface Potentials and EMG Responses of the Extraocular Muscles

In this experiment the retina was not removed. After incising the bulbar conjunctiva, bipolar needle electrodes were inserted into the dorsal rectus (Channel 3), medial rectus (Channel 4), ventral rectus (Channel 5), ventral oblique (Channel 6), levator palpebrae superioris (Channel 7), dorsal oblique (Channel 8), and lateral rectus (Channel 9) muscles. The oculomotor nerve distributes to the first five muscles (Channels 3–7) and the trochlear and abducens nerves distribute to the dorsal oblique (Channel 8) and lateral rectus (Channel 9) muscles, respectively. Electromyography responses of extraocular muscles and evoked potentials obtained from the surface electrodes were simultaneously recorded. The ground was a needle electrode inserted into the ipsilateral temporal muscle.

Sources of Supplies and Equipment

The surface electrodes (model 019-721900), silver-ball electrodes (model 45182, 1 mm in diameter), and stainless-steel needle electrodes (model 45244) were acquired from NEC Medical Systems Corp. (Tokyo, Japan). The electrodes were connected to the isolator (model SS-101J) of an electrical stimulator (model SEN-1101), both of which were manufactured by Nihon Kohden Corp. (Tokyo, Japan). An NEC signal processor (model 7T07A) and an NEC X-Y recorder (model 8U16) were used to assess the evoked responses.

Results

A summary of the experimental protocols and results is presented in Fig. 1.

Recording of Surface Potentials

Highly reproducible evoked potentials were recorded from the surface electrodes (Fig. 2). The stimulation threshold, peak latency, and amplitude of the first large peak in each nerve stimulated by 2 mA are shown in Table 1. The parameters could be easily changed by moving the recording electrodes. There were many individual differences. On stimulation at the stimulus threshold, no eye movement was observed. Stimulation of the oculomotor and abducens nerves with increased stimulus current resulted in eye movement; however, no eye movement was observed when the trochlear nerve was similarly stimulated. The waveforms were almost identical with or without eye movement. The latencies, amplitudes, and waveforms were almost the same for the two types of bandpasses. Sectioning of the oculomotor nerves resulted in the disappearance of all evoked potentials.

Effect of Removing the Retina

The thread sutured to the center of the cornea was pulled horizontally, and evoked potentials were recorded from surface electrodes during the resultant eye movements (Figs. 1 and 3). These potentials were confirmed to originate in the eye because they manifested the same waveforms after the administration of muscle relaxant. After removal of the retina, the amplitudes disappeared almost completely. After administration of a muscle relaxant, the potentials completely disappeared. Surface potentials elicited by oculomotor nerve stimulation were the same before and after removal of the retina.

Simultaneous Recording of Surface Potentials and EMG Responses of the Extraocular Muscles

Stimulation of the oculomotor nerve by 1 mA produced EMG responses of the dorsal rectus, medial rectus, ventral rectus, ventral oblique, and levator palpebrae superioris muscles. Trochlear nerve stimulation at 2 mA elicited EMG responses from the medial rectus muscle. Stimulation of the abducens nerve at 1 mA produced EMGs from the lateral rectus muscles. Evoked potentials recorded from the surface electrodes were almost identical to those represented by EMG responses recorded from the extraocular muscles with respect to peak latencies, amplification.
Surface potentials evoked by oculomotor nerve stimulation

Muscles in their peak latencies and amplitudes. When different nerves were stimulated at 1 mA, EMG responses of muscles supplied by the nerves were produced. Increasing the stimulus intensity to 3 mA resulted in the production of EMG responses from muscles not innervated by the nerve. The potentials elicited at 1 and 3 mA were identical, indicating that the EMG responses were indirectly recorded from muscles not innervated by the nerve. When the trochlear nerve was stimulated at 2 mA, EMG responses were recorded from the medial rectus muscle, but not from the dorsal oblique muscle. The needle electrodes were inserted into the tendon of the dorsal oblique muscle because it was impossible to insert them into the proximal portion of the muscle without damaging other structures. Because the electrodes in the medial rectus muscle were nearest to the dorsal oblique muscle, signals from the former were recorded first when the trochlear nerve was stimulated. Because the bandpass range reportedly influences potentials recorded from surface electrodes, we examined the effect of the two types of bandpass. Our observation that the bandpass range had no effect on the waveforms confirms that the potentials that were recorded originated in muscle. Therefore, we posit that the evoked potentials recorded from the surface electrodes originated from the extraocular muscles.

<table>
<thead>
<tr>
<th>No. of experiment</th>
<th>Nerve stimulation</th>
<th>Pulled eye movement</th>
<th>Muscle relaxant</th>
<th>Removal of the retina</th>
<th>Surface electrodes</th>
<th>Muscle electrodes</th>
<th>Typical waveform</th>
<th>Origin of waveform</th>
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<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>−</td>
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<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
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<td>1 mV</td>
<td>EOG+EOG?</td>
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<tr>
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<td>−</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
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<td>1 mV</td>
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<td>−</td>
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<td>+</td>
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<td>+</td>
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<td>−</td>
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<td>−</td>
<td>0.1 mV</td>
<td>EMG+EOG?</td>
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</table>

Fig. 1. Summary of experimental protocol and results. + = performed or used; − = not performed or used.

TABLE 1

<table>
<thead>
<tr>
<th>Thresholds, peak latencies, and amplitudes of evoked potentials in each nerve in response to stimulation at 2 mA</th>
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<tr>
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<tr>
<td></td>
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<tr>
<td>III</td>
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<td>VI</td>
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</table>

Fig. 2. Basic waveforms recorded from surface electrodes placed on cranial nerves three, four, and six. Channel 1, horizontal; Channel 2, vertical.
Conclusions

Evoked potentials elicited by electrical stimulation of the oculomotor nerves and obtained from surface electrodes originate in the extraocular muscles. They do not derive from the eye and thus EOG does not provide an appropriate representation.

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References


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