Comparison of Electrical Parameters and the Quality of Electro-Anesthesia

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Studies were conducted to characterize electro-anesthesia in cats and to provide insight into inter-relations of various electrical parameters. Data were obtained from 138 trials in 20 cats with a pair of subcutaneously implanted palladium wire electrodes, one located between the eyes and the other at the occiput. Current was provided by an instrument which delivered square-wave pulses automatically elevated above the zero potential base-line, which could be adjusted to various pulse durations and periods. Satisfactory anesthesia could be produced in cats without supplemental drugs or artificial ventilation. Assessment of pain reflexes during electro-anesthesia led to the suggestion that electrical current produces analgesia in ways not yet elucidated. Elevation of the electrical waveform above the base-line was not beneficial. Several residual effects were noted to persist for a short time after electro-anesthesia. The results also disclosed the importance of the relationship of the waveforms' pulse duration and period. Waveforms with small ratios were the most effective in terms of achieving anesthesia with the least amount of average current.

In spite of the great interest in electro-anesthesia, in human and veterinary medicine, there are many problems and objectionable side-effects.1-4 Because it is generally assumed that the solution to these problems will be found by investigation of various electrical parameters, this research emphasized the influence of square-wave frequency and pulse duration on anesthesia quality. The relation of frequency to the quality of electrical anesthesia requires clarification, as illustrated by the rather extensive range of frequencies preferred by investigators in various laboratories.1,3,5,6 Moreover, previous reports5,6 have emphasized the importance of pulse duration, yet have not clarified its role.

Another goal of this research was to characterize the state of electro-anesthesia in the cat. To the authors' knowledge no systematic electro-anesthesia studies have been conducted in this species, in spite of its widespread use in neurophysiological research. One published study refers to the effects in cats, but only briefly.3

This present research also includes a test of the hypothesis that previous electro-anesthesia experience influences the response to subsequent experiences, as suggested by reports of postanesthesia analgesia.2 This study likewise includes a test of the concept of some workers, especially of Smith and his associates,2,5,7 that the quality of anesthesia can be improved by employing direct current to elevate the waveform above the zero potential base-line.

Methods

There were two major types of experiment: (1) those designed to characterize electro-anesthesia in the cat, using many trials with a single set of electrical parameters, and (2) those designed to test the effects of various electrical parameters on the quality of anesthesia produced.

Data were obtained from 138 trials in 20 adult cats. Each cat underwent 7 randomly selected trials which were administered on alternate days. Prior to each trial, cats were sedated with 20 mg./kg. sodium pentobarbital, injected intraperitoneally. Preliminary experiments revealed that if cats were restrained in a "cat bag" during induction of electro-anesthesia no premedication of any sort was required. However, the bag interfered with reliable assessment of animal reactions. The
degree of sedation was such that restraint was unnecessary, yet all pain reflexes were present. No other drugs were used, nor was the trachea intubated and ventilation provided.

**Current Generator.** The current generator delivered square-wave pulses which could be adjusted in terms of pulse duration and frequency. The waveform could be automatically elevated above the base-line, if so desired, without flow of d.c. current through the animal. The circuitry and more specific description have been previously described.8

**Stimulus Parameters.** During all trials the dimensions and shape of the waveforms were observed on an oscilloscope. The initial study characterizing electro-anesthesia in the cat employed a frequency of 100 c.p.s. with 3 m/sec. pulses of unidirectional polarity. The influence of polarity was studied by including a trial on each animal with bi-directional waveform.

In the test of various electrical parameters, particular note was directed toward the ratio of pulse duration to the period. The following pulse durations, frequencies and pulse duration-period ratios were employed: 0.7 m/sec., 100 c.p.s., 7 per cent; 2 m/sec., 66 c.p.s., 13 per cent; 3 m/sec., 66 c.p.s., 20 per cent; 3 m/sec., 100 c.p.s., 30 per cent; 0.8 m/sec., 526 c.p.s., 42 per cent; and 1 m/sec., 700 c.p.s., 70 per cent.

**Electrode Placement.** Palladium wire electrodes were implanted subcutaneously at a distance of 25 mm. along the long-axis midline, one over the external occipital protuberance and the other midway between the eyes and extending over the nasal bones. In 8 of the cats the latter electrode was positioned more posteriorly, beginning at the medial canthi and extending over the frontal bones. The polarity of the occipital electrode was always negative. Palladium was chosen because "anodic back potential" studies have shown that its degree of inertness is comparable to that of platinum and because it resists the polarizing effects of direct current.8

**Scoring System for Induction Severity.** Because one goal of this research was to investigate the influence of various electrical parameters on the severity of animal reactions during induction, a scoring system was devised to allow accurate quantification. Preliminary studies revealed that there were certain animal responses by which one could distinguish various stages of induction. The induction scoring system and the observed progression in animal reactions are summarized in table 1. The induction period was arbitrarily divided into 3 ranges of current: 0–4, 4–7, 7–10 ma.

**Induction Procedure.** The procedure for induction consisted of increasing current levels as fast as possible without producing prolonged apnea. The time required for induction was noted for each electrical parameter. An upper limit of 5 minutes was arbitrarily selected at which the experiment was terminated if induction could not be completed.

**Assessment of Depth of Anesthesia.** Animals were generally given enough current to produce an optimal state of anesthesia, at which time the total amount of current required was noted. Optimal anesthesia was defined as that level at which pain reflexes were abolished at the ear, flank, and tail and at which there were no undesirable side-effects. The adequacy of these indicators was demonstrated at the end of the experiments on each cat by performance of laparotomy.

**Laparotomy and Post-mortem Examination.** At the end of the experiments, 10 cats were subjected to a laparotomy through a left-flank incision during a state of optimum anesthesia, as previously defined. The adequacy of the superficial pain reflexes as indicators of anesthetic depth was checked by noting absence.
Table 2. Characteristics of Electro-Anesthesia in Cats

<table>
<thead>
<tr>
<th>Stimulus: 3 msec. pulses, 100 c.p.s.</th>
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<tbody>
<tr>
<td>Induction severity score and S.E.</td>
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<tr>
<td>0–4 ma.</td>
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<tr>
<td>4–7 ma.</td>
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<tr>
<td>7–10 ma.</td>
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<tr>
<td>Induction time</td>
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<tr>
<td>S.E. (minutes)</td>
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<tr>
<td>Average current required (ma.)</td>
</tr>
<tr>
<td>Pain Reflexes (number cats with reflex/total number cats)</td>
</tr>
<tr>
<td>Cornet</td>
</tr>
<tr>
<td>Pupillary</td>
</tr>
<tr>
<td>Ear</td>
</tr>
<tr>
<td>Flank</td>
</tr>
<tr>
<td>Tail crush</td>
</tr>
<tr>
<td>Hind toe</td>
</tr>
<tr>
<td>Front toe</td>
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*Values obtained when a second induction was given, immediately after the first.

of response to incision and subsequent compression, stretching, and distortion of the liver, kidney, small intestine, and large intestine. After the laparotomy and subsequent sacrifice, the area around the electrodes was examined to determine the nature and extent of burns.

Results

Characterization of Electro-Anesthesia. During a portion of the induction period, most of the cats sneezed. The current range at which this occurred varied widely but in a given animal tended to be constant. All 12 cats with the positive electrode over the nasal bones sneezed during delivery of 4–8 ma. Of the eight cats with the anode placed more over the frontal area, only 4 sneezed.

At the end of the 10 ma. induction period, the induction severity scores averaged 2.4 ± 0.07 (table 2). At this current level the corneal reflex was always absent; pain reflexes were always present and the pupillary size and response to light were normal.

During optimal anesthesia the total amount of current employed averaged 15 ± 1 ma. (table 2). Corneal, flank, and ear reflexes were always absent; however, digital flexor reflexes were present in some of the cats. The tail reflex was never present, since it was used as an end-point in determining optimal anesthesia. The pupil was commonly constricted to a vertical slit and showed no response to darkness; moreover, constriction persisted after termination of the electrical stimulus.

Previous electro-anesthesia clearly influenced the responses to subsequent delivery of current (table 2). It was evident that a second exposure to current immediately after the first was characterized by lower induction severity scores and a shorter induction time. The duration of facilitation of induction was not studied systematically, but it was observed in one animal as long as 1 hour after the initial anesthesia period.

Elevation of the stimulus waveform above the base-line did not reduce umnward reactions. In fact, the induction severity scores were the same, whether or not the waveform was elevated. Changing the waveform position relative to the base-line after induction did cause corresponding motor reactions in the cats.

![Fig. 1. Amount of average current (± S.E.) required for complete anesthesia, plotted as a function of the pulse duration-period ratio of the electrical current.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931628/)
Laparotomy elicited no signs of pain in 7 of the 10 cats. Three cats made audible sounds ordinarily associated with pain, although they exhibited no pain when the coccygeal vertebrae were compressed between the jaws of a needle forceps. Visceral pain was abolished in each case by administering 3-4 ma. of additional current.

Burns along the electrode tracks averaged 2-3 mm. in diameter. All of the anterior electrode sites were surrounded by a tract of necrotic tissue, as were 7 of the 10 posterior electrode sites.

Influence of the Stimulus Pulse Duration-Period Ratio. Determinations of the average amount of current required to produce optimal anesthesia revealed that those waveforms with the smallest pulse duration-period ratios produced optimal anesthesia with the least amount of current. A plot of these ratios as a function of the total amount of current required is shown in figure 1. The value for a 70 per cent waveform is not shown because anesthesia was never produced with the maximum current employed (30 ma.). The graph illustrates the following:

![Graph showing induction severity scores as a function of pulse duration-period ratio](image)

**Fig. 2.** Average induction severity scores, plotted as a function of the pulse duration-period ratio of the electrical current. ▲ 0-4, ○ 4-7, ● 7-10 ma.

<table>
<thead>
<tr>
<th>Stimulus (c.p.s.)</th>
<th>Total Current Required (ma. ±S. E.)</th>
<th>Induction Severity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-4 ma.</td>
<td>4-7 ma.</td>
</tr>
<tr>
<td>600</td>
<td>0.5</td>
<td>26.5 ±1</td>
</tr>
<tr>
<td>100</td>
<td>3.0</td>
<td>18.0 ±2.3</td>
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(1) At the same frequency, the current required increased with increasing pulse duration. (Compare values of 7 per cent with 30 per cent and 13 per cent with 20 per cent.)

(2) At the same pulse duration, the current required increased with increasing frequency. (Compare value of 20 per cent with 30 per cent.)

(3) At variable levels of frequency and pulse duration, the current required increased with increasing pulse duration-period ratios.

Waveforms with small pulse duration-period ratios were also shown to produce the most severe reactions during induction. The plot of these data (fig. 2) illustrates the following for each range of average current:

(1) At the same frequency, the induction severity decreased with increasing pulse duration. (Compare scores of 7 per cent with 30 per cent and 13 per cent with 20 per cent.)

(2) At the same pulse duration, the induction severity decreased with increasing frequency. (Compare score of 20 per cent with 30 per cent.)

(3) At variable levels of frequency and pulse duration, the induction severity decreased with increasing pulse duration-period ratios.

This decrease in induction severity was accompanied by a parallel decrease in induction time, which decreased progressively from an average of 5 minutes for a 7 per cent stimulus to 1.9 minutes for a 70 per cent stimulus. This relation between the pulse duration-period ratio and the effectiveness of the stimulus has been confirmed in preliminary experiments in rabbits.

Finally, a study in which two waveforms were compared, each with the same ratio (30 per cent) with different frequencies, revealed distinct differences in anesthesia, despite the same pulse duration-period ratio. With the
faster frequency, more current was required to attain anesthesia and the average induction severity scores were less (table 3).

Discussion

The study revealed that electro-anesthesia can be accomplished safely in the cat without such supportive measures as autonomic drugs, muscle relaxants, and tracheal intubation and ventilation. The induction severity scoring system was a reliable method for quantifying the progression of reactions during induction and for comparing various electrical parameters. The association of the degree of sneezing with electrode proximity to the nasal area suggests that the sneezing is due to local action of current on nerves in the area. The variability in persistence of pain reflexes, especially in the viscera and toes, may suggest that electrical current produces analgesia in ways not yet elucidated that are different from drug-induced analgesia.

The fact that there is a delay before normal function returns after cessation of electro-anesthesia is clearly supported by the findings of persistent pupillary constriction and by the facilitation of a subsequent induction.

The pulse duration-period ratio data suggest that narcosis is due to the stimulating properties of the waveforms, an idea that was advanced for other reasons many years ago. These data also clearly indicate that the effectiveness of a waveform is largely dependent on its pulse duration-period ratio, and that in the cat stimuli with the smaller ratios are the most effective. Independent of the ratio, frequency may have some influence of its own, as shown by the comparison of two stimuli of different frequency but the same ratio.

Summary

Results of a systematic electro-anesthesia study in cats are reported. In addition to characterizing feline electro-anesthesia, the study confirms the hypothesis that initial electro-anesthesia can influence the course of subsequent electro-anesthesia. The study failed to detect any beneficial effects from elevating the a.c.-origin square-wave above the zero-voltage baseline. Moreover, the study disclosed the importance of the relationship of pulse duration to the period of the waveform, in that those with small ratios were the most effective in terms of achieving anesthesia with the smallest levels of average current. With the highest ratio employed, anesthesia could not even be achieved.

References