EXPERIMENTS IN ELECTRONARCOSIS:
A PRELIMINARY STUDY

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The production of narcosis by means of electrical currents in animals and man has been attempted by many investigators. Although some were successful in part, the satisfactory application of electrical currents as general anesthesia was not attained by the early investigators because of cyanosis, bradycardias, cardiac irregularities, and severe muscular contractions which developed under electronarcosis. It was thought that some of these difficulties might be eliminated by the application of modern techniques of anesthesiology and it was with this thought in mind that the present investigations were undertaken.

HISTORY

Constant Direct Current

As early as 1875 a Vienna physicist, Mach (1), narcotized fish by means of a constant direct current. Silver and Gerard (2) passed an uninterrupted direct current between nonpolarizable electrodes placed in the mouth and anus of frogs, rats, and dogs, and were able to produce and maintain a state of apparent narcosis. In the frog as little as 3 milliamperes, in the rat 12 milliamperes, and in the dog 40 milliamperes were sufficient to maintain an inactive state. One dog was maintained in apparent narcosis for eight hours. The recovery time was very short in the frog and rat, but the dogs required 100 minutes for full recovery. Blood pressure and pulse were not changed significantly.

Interrupted Direct Current

In 1890 d'Arsonval (3) used a direct current interrupted 2,500 to 10,000 times a second to cause anesthesia in rabbits. Leduc (4) devised an apparatus which generated interrupted direct currents in varying frequencies, strengths, and voltages. He used a current of 0.5 to 10 milliamperes, voltages of 7 to 50, and frequencies of 100 cycles per second with the current on one-tenth of the total time to anesthetize.

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animals and, after experience had been gained, to anesthetize himself. Two of Leduc's associates, Roxeau and Malherbe, applied the current until Leduc felt a sensation of numbness, loss of motor function and hearing. Hertz (5), using Leduc's current on 5 human beings, concluded that true anesthesia could not be obtained since the subjects reported that although they could not move when stimulated by pinching of the skin with forceps, they were aware of the stimulation. Cyanosis during the application of the current, a sense of suffocation and death, and severe muscle contractions were other objections to the direct interrupted current. Ivy (6) believed that better results were obtained in animals with Leduc's current if a current which was on three-tenths of the total time at 72 volts with a frequency of 100 cycles per second was used. After this current was applied to an animal for fifteen seconds an "anesthesia" lasting about two minutes was achieved. Following the application of the current a marked fall in blood pressure, as well as arrest of respiration, occurred. Ivy could not be absolutely certain that true anesthesia occurred but evidence of loss of consciousness was strongly presumptive. Denier (7) stated that electrocardiograms taken a few minutes after the cessation of Leduc's current showed auricular fibrillation which disappeared after about thirty minutes. Scheminsky (8) believed that Leduc's current did not cause a true narcosis because of the accompanying muscular convulsions and, furthermore, that a true "chemical narcosis" could be obtained only from a constant direct current. Rose and Rabinov (9), in 1945, used intermittent direct current produced by electronic oscillators to produce narcosis in rats, rabbits, cats and monkeys. They found muscular relaxation greatest in the monkey and that the higher the classification of the animal on the phylogenetic scale, the better the anesthesia produced. Laryngeal crowing was noticed with occasional slowing of the pulse. After the anesthesia no untoward effects were noticed in the animals. Von Neergaard (10) compared the disadvantages of intermittent direct current, the narrow therapeutic range, the doubtfulness of the existence of true narcosis, the increased muscular contractions preventing surgery, the decreased respiration, the bradycardias and cardiac arrests with the advantages of absence of toxicity and complete and immediate reversibility of the process, and concluded that the current was practical for animal experiments, but should not be applied to man.

**Alternating Currents**

Alternating currents were first used to produce electronarcosis by van Harreveld and Kok in 1934 (11). Van Harreveld, Plesset and Wiersma (12) found the most satisfactory method for producing electronarcosis was to apply a strong sinusoidal alternating current of about 300 milliamperes for about thirty seconds at a frequency of 60 cycles per
second, after which the current was dropped to a lower level. Two types of electronarcosis developed from this current. The first was the narcotic type in which the animal remained quiet with slow and deep respirations which were often accompanied by glottis contractions. The heart rate was slow, about half of normal. The second was the kinetic type of electronarcosis in which the animal made frequent attempts to right himself. In this latter type of electronarcosis the heart and respiration rates were higher than in the narcotic type. They found that the electronarcotic effect of direct current was small when compared with that of pulse or alternating current, and concluded that electronarcosis is due to the stimulating properties of the current applied.

Because some of the difficulties with respiration and circulation which these early experimenters found in electronarcosis were similar to problems faced in any general anesthesia, it was thought that they might be solved by the application of modern techniques of anesthesiology.

Use of Modern Techniques of Anesthesiology in Electronarcosis

A. Electronic Equipment for Electronarcosis (fig. 1)

The electronic equipment consists of an oscillator, an amplifier and an oscilloscope for monitoring the output of the amplifier. Current and voltage strength as well as wave form are constantly monitored during the electronarcosis.

The oscillator provides a sine wave signal of variable amplitude and variable frequency to the amplifier. Its frequency limits are 20 to 20,000 cycles per second.

The amplifier is capable of producing currents up to 300 milliamperes through a load resistance of 200 to 300 ohms, and maintains constant current over the load range from 200 to 1,000 ohms for reduced currents. The constant current mechanism (fig. 2) is a feed-
back loop consisting of a resistor in series with the load and connected in such a manner that an increase in load current produces a voltage which tends to reduce the input to the amplifier until a constant load current balance is achieved. The load current is varied by changing the output amplitude of the oscillator.

The output circuits of the amplifier include a dummy load resistor of 250 ohms which simulates the resistance of the subject while making preliminary calibration of the oscilloscope. The output of the amplifier is switched from this dummy to the subject when the experiment is in order and back to the dummy when completed or in case of emergency. This allows the current to be removed from the subject and returned without the usual warm-up period for the amplifier.

Also provided in the output circuits are connections for an oscilloscope so that either load current or load voltage can be monitored by changing the position of a switch.

**CONSTANT CURRENT MECHANISM**

Fig. 2. The constant current mechanism is a feedback loop consisting of a resistor in series with the load and connected in such a manner that an increase in the skin resistance of the subject will cause an increase in the input to the amplifier, resulting in an unchanging current flowing through the subject.

The measuring equipment consists of an oscilloscope for measuring load currents or observing wave forms and a vacuum tube voltmeter for measuring voltage across the load.

**B. Production of Electronarcosis**

All experiments were conducted upon dogs. Evidently the production of electronarcosis was not an unpleasant experience for although the animals were given electronarcoses repeatedly, none exhibited any evidence of fear before or after the procedure. Silver electrodes the size of twenty-five cent pieces were fastened to the animal's shaved head by means of a rubber strap, tied loosely so as to permit free respiration. Electrode paste was placed beneath the electrodes. The animals were placed in hammock-like supports, so constructed that their legs were free, which permitted venipuncture and manipulation for various measurements. As the electronarcotic current was applied...
the animal went into extensor spasm, breathing ceased, and urination and defecation occurred. The pulse decreased markedly, and frequently became irregular. This initial state lasted about ten to twenty seconds and then the muscular rigidity decreased, the animal began to breathe slowly and regularly. The tongue was cyanotic. At this point the animal appeared to be narcotized: there was no reaction to painful stimuli, the eyes were closed, and voluntary movements were absent. This state may be maintained for an indefinite length of time, although it is not advisable unless a good airway is maintained. When the current is turned off, the dog immediately opens his eyes, and appears to be without any ill effect from the electronarco.

The electrode contact must be absolutely secure and the line voltage must not vary if quiet narcosis is to be maintained. Early in the experiments we noticed intermittent periods of excitement during prolonged narcosis. As soon as we correlated the turning on of a refrigerator in the laboratory with the periods of excitement, we were able to change our equipment to a different line and obtain quiet narcosis. Although it could not be detected on our oscilloscope, a transient line voltage drop undoubtedly occurred. Variations in line voltages and inadequate electrode contacts undoubtedly explain some of the difficulty in obtaining quiet electronarco.

Large currents (80 to 125 milliamperes) caused violent tonic and clonic convulsions in our animals and following the electronarco the animals were dazed for several minutes. Smaller alternating sinusoidal currents, ranging from 25 to 75 milliamperes at frequencies of 700 to 1,500 cycles per second were found to produce electronarco with less initial tonic spasm and without clonic convulsions. It was not found necessary to increase the current strength to maintain the electronarco over periods up to an hour.

It was thought that perhaps a slow "induction," analogous to the slow inductions that we use with other general anesthetics, might eliminate some of the undesirable features of electronarco. This did not, however, prove to be the case. When the current strength was slowly increased, the animal became increasingly excited until a current strength was reached far in excess of that which previously had caused electronarco. With this high current electronarco was produced, but it was usually unsatisfactory because of continued restlessness of the animal. This probably was attributable to poor electrode contact caused by the animal's movements.

C. Technique of Intubation

With the onset of electronarco the masseter muscles are in spasm as are the other muscles of the body. Although the other muscles relax in ten to twenty seconds, the masseter muscles remain in spasm, probably as a result of direct stimulation by the electrical current. Endo-
tracheal intubation cannot be accomplished without the aid of auxiliary drugs. *D*-tubocurarine chloride, 1 mg. per 10 kg. of body weight, was given intravenously as soon as the animal was narcotized. Within one minute the jaw could easily be opened, an Allis clamp applied to the tongue and pulled forward, and an endotracheal tube inserted without difficulty. The animal then remained well oxygenated, as judged by color of the tongue during the rest of the electronarcosis. Measurements of respiratory function also may easily be made.

The dog's head, jaws, tongue, and the metal endotracheal tubes may be handled without danger of electrical shock.

**D. Use of Atropine in Electronarcosis**

Atropine sulfate, 0.006 mg. per kilogram of body weight, given intravenously fifteen minutes before the production of electronarcosis prevented the occurrence of severe bradycardias and seemed to prevent the occurrence of serious cardiac irregularities usually seen in electronarcosis. Although a slight fall in pulse rate occurred, this was negligible when compared to the bradycardia seen in the unatropinized dog. In one dog which had been given an unatropinized electronarcosis, severe bradycardia of 58 beats per minute had developed, with marked irregularity. After the animal had recovered from the electronarcosis, it was given atropine sulfate, 0.006 mg. per kilogram of body weight, intravenously. When electronarcosis was given fifteen minutes later, the cardiac arrhythmia disappeared, but the pulse remained at about 50 per minute. When the electronarcosis was terminated the pulse had risen to 120 per minute and was regular. Atropine also prevented the formation of excessive mucus which usually accompanies electronarcosis.

**E. Use of Barbiturates with Electronarcosis**

It was hoped that the use of barbiturates would prevent the occurrence of the initial tonic convulsion, but this has not been obtained in our experiments. Pentobarbital® sodium, 10 mg. per kilogram of body weight, was given intravenously five minutes before electronarcosis. Although the initial tonic spasm was lessened in its intensity, it was not eliminated. No difference was noticed in the electronarcosis produced.

**F. Application of Electronarcosis to Animal Surgery**

Several operations have been performed on dogs under electronarcosis. The following is an electronarcosis record of our first operation on a dog, a pyloric division and insertion of cannula into the stomach:

2:40 Electronarcosis was begun; 50 milliamperes, 700 cycles per second, voltage 30, was applied to the dog without effect. The
current was increased to 55 milliamperes and electronarccosis developed. The dog was placed on the operating table. \textit{D}-tubocurarine, 1 mg. per 10 mg. of body weight, was given intravenously.

2:42 An endotracheal tube was inserted with slight difficulty because of tension of the tongue. The automatic breathing apparatus was connected to the endotracheal tube.

2:43 The pulse was 76 per minute; the tongue was pink. The current was 55 milliamperes and voltage 30.

2:50 Skin towels were clamped on; the dog moved his head slightly.

2:52 An incision was made in the upper part of the abdomen. The animal made no movement. Operator felt a shock "like prickles of cactus" when he put his hand into the abdomen in blood. He wore shoes with nails in the soles and was standing in water. After he sat on a wooden stool he did not notice shock. He stood on a wooden block for the remainder of the operation.

2:56 The dog moved when a Balfour retractor was applied. The current was increased to 60 milliamperes. After a moment the dog lay quiet again.

3:02 Operation and narcosis proceeded satisfactorily.

3:04 The endotracheal tube came loose from the breathing apparatus. The dog's head was moved, which resulted in struggling. The current was 60 milliamperes and the dog soon lay quiet.

3:12 Narcosis and operation proceeded satisfactorily.

3:32 Whenever the dog's head was moved, for example, to demonstrate the position of the electrodes on the head, a period of excitement followed. The current was increased to 65 milliamperes.

3:44 The skin was closed.

3:46 The current was turned off. The dog awakened immediately. Nystagmus was present in both eyes. The dog was still lying down, but held its head up.

3:55 Tensilon, 10 mg., was given intravenously. Nystagmus was still present, and the dog could not walk well.

3:56 The dog walked around well. Nystagmus was still present.

4:05 Nystagmus was almost gone. The dog appeared to be normal.

\textbf{Summary}

Using an electrical apparatus which maintained a constant current despite changes in skin resistance, electronarccosis was produced in dogs. Sinusoidal alternating currents of 25 to 80 milliamperes with frequencies of 700 to 1,500 cycles per second produced the most desirable electronarccosis. Endotracheal intubation, accomplished with the assistance of intravenous \textit{d}-tubocurarine chloride, eliminated the poor oxygenation which usually accompanies electronarccosis. Atropine
sulfate, given intravenously fifteen minutes before electronarcosis, markedly diminished the bradycardias and cardiac irregularities that usually accompany electronarcosis. The intravenous administration of pentobarbital sodium did not abolish the initial tonic spasm and did not interfere with the production or maintenance of electronarcosis.

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