Review

Electrical Anesthesia

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ELECTRONARCOSIS has had recurrent interest for many years. The earliest work appears to be by Mach,[26] who narcotized fish in 1875 by means of constant direct current. Constant current was also tried by Silver and Gerard[31] in 1941. The first extensive investigative work was that of Leduc,[22] who attempted electronarcosis on animals and on himself using direct current interrupted by a rotating commutator. He found that electronarcosis was best produced by a wave form which was on about 10 per cent of the time and off about 90 per cent of the time. Although application for clinical surgery has been cited by Paterson and Milligan,[27] examination of the original French literature (Tuffier and Jardry, 1907)[37] has disclosed that the only experiments were on five dogs. Leduc's findings and opinions are remarkably similar to material which has appeared in the recent literature. An extended quotation seems justified. The translation was supplied by Dr. Andre Smessaert (St. Vincent's Hospital, New York).

"Until 1870 the unexcitability of the brain by electricity (constant direct current) was a physiological dogma.

"Vertigo also appears in man (as well as in rabbits); *it is caused by changes in intensity of current* [italics mine] and its maximum is produced at the sudden establishment of the circuit. The vertigo is more intense when the direction of the current nears the transversal axis of the head, which means that the difference of potential between the two cerebral hemispheres is pronounced. The vertigo diminishes after the closure of the circuit, but for a given intensity it does not disappear entirely during the passage of the current. It persists also for a few moments after the opening of the circuit. By giving the current an anterior-posterior direction in order to distribute the current symmetrically in each hemisphere, and by gradually varying the intensity, vertigo is avoided. Furthermore, vertigo varies from one subject to the other."

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Leduc discussed in detail the widely varying reports concerning nystagmus, muscle contraction, and effects on cerebral circulation. His summary of animal experimentation remains true after 60 years: "Due to the experimental difficulties connected with the subject, we can only accept these indications as expression of an opinion, and one must wait for better means in order to obtain more precise information on the subject."

Leduc also theorized on the mechanism of action of continuous currents and thought that migration of ions was the cause of many of the observed effects. Perhaps his most important contribution was the concept of periodic interruption of the current. He found that an effect could be obtained with a minimum current which was on 10 per cent and off 90 per cent of the time. His description of gradual induction is remarkably similar to those of Anan'ev *et al.*[3] and Smith and Volpitto.[32] He also commented on "the continuous discharge of liquid from the mouth and the nasal passages."

Leduc's success with animal experimentation led him to try it on himself. "We have submitted ourselves to the action of electrical cerebral inhibition. A large electrode formed by cotton impregnated with a solution of sodium chloride on a metal plate was placed on the forehead and attached around the head; this frontal electrode was the cathode. A very large electrode made in the same fashion was fixed in the lumbar region with a rubber band. The electric current, passing 100 times per second during one-tenth of each period, was gradually established. The sensation caused by excitation of peripheral nerves although unpleasant is easily bearable; this sensation quiets down as time goes by just as the sensation caused by continuous current. After passing through a maximum, it diminishes, notwithstanding the increase of the electrical current. The face is red, moderate contractions of the face muscles and even of the muscles of the neck and forearm take place. Following this, one feels a tingling in the extremities of the fingers and the hands. This tingling spreads to the feet and toes. The inhibition first reaches the centers of speech and then the motor centers. The subject is unable to react even to painful stimulations; he cannot communicate any more with the experimenter. The extremities, without being completely relaxed, do not show any stiffness. The subject has some stridor; this is not related to any painful sensation, but seems caused by stimulation of muscles of the larynx.

"In our experiments, the pulse was unchanged; respiration was a little difficult. When the current was at its maximum we could still hear as if in a dream what was said around us; we were conscious of our inability to move or to communicate with our colleagues. We did feel contacts, pinching, and pinprick in the forearm, but the sensation was blunted as if the extremity was numbed. The most unpleasant feeling is to be aware of the dissociation and progressive disappearance of the faculties. This sensation is identical to a nightmare during which, in the presence of great danger, one would feel unable to talk or to move."

Leduc encouraged the use of electricity for the treatment of cerebral diseases rather than the production of anesthesia. The use of electricity to produce unconsciousness and convulsive seizures was introduced for the treatment of psychotics by Cerletti and Bini[8] in 1938 as a safer and less unpleasant substitute for insulin coma or pentamethethylene tetrazol convulsions, during which the patient was conscious. The success of electroconvulsive therapy prompted an examination of various wave forms. In 1922, von Neergaard[41] repeated Leduc's experiments, obtaining similar results, but concluding that the current caused stimulation rather than depression.

In 1932, Ivy and Barry[17] used mechanically interrupted direct current for stunning dogs, and noted a loss of reaction to painful stimuli which lasted from 55 seconds to 12 minutes. This apparent analgesic action has been noted by other investigators, including Anan'ev,[3] Hardy *et al.*,[16] and Smith *et al.*[32, 33]

In 1934, van Harrevald and Kok[38] applied alternating current to the heads of dogs to obtain seizures followed by coma. In 1942, van Harrevald *et al.*[39] measured the relationship between frequency of alternating current and amperage necessary for a given depth of narcosis and showed that the most effective frequencies were between 50 and 100 cycles per second. A constant-current instrument was devised which would compensate for changes in the patient's skin resistance. The maximal stimulating effect at the lowest amperage was sought, since it was believed that remission of mental disease was favored by these conditions.

It is important to note that the anesthesiologist investigating electronarcosis seeks only a transient change in the patient's perceptive ability with no postanesthetic sequelae, but the psychiatrist seeks far-reaching modifications of the patient's subsequent behavior and regards the period of unconsciousness as only the beginning of the treatment. As presently practiced, electric-convulsive therapy (ECT) consists of bitemporally applied 60-cycle alternating current of sufficient intensity and duration to produce a grand-mal seizure. About 100 volts for 0.1 second is often sufficient, but voltage and time may be increased if a refractory state develops during the course of treatments. Skin resistance is reduced by means of electrode paste. Because of the brief application of current, burns are less common during ECT than during extended sessions of electronarcosis.

Electronarcosis thus had its origin in conflicting opinions, and this pattern has continued to the present day. The reviewer finds it difficult to separate fact from fancy, and even to decide on the meaning of the term, since "electronarcosis" has one meaning to anesthesiologists and quite another meaning to psychiatrists. Most of the publications on electronarcosis are in the psychiatric literature and pertain to the use of sustained subconvulsive-electroshock currents in the treatment of mental disease. A short excerpt from a representative article will serve to indicate that the psychiatrist's form of electronarcosis is of little interest to the anesthesiologist who wishes to produce safe effective reversible near-physiologic sleep during which surgery may be performed. Bowman and Simon [5] describe the Tietz technique of electronarcosis for the treatment of schizophrenia and conclude that it is more dangerous and less simple to administer than electroshock. An extensive quotation from their section on "Reaction During Electronarcosis" will serve to illustrate some of the problems inherent in electrical anesthesia.

"When the current is switched on suddenly there is an immediate tonic flexion of the extremities and of the torso (jack-knifing). . . . There is usually a period of cardiac arrest; at least heart sounds cannot be heard for a period of 0 to 30 seconds (usually between 5 to 10 seconds) after which the heart rate is slow (as low as 30 per minute) and rhythm irregular. The face, neck, and upper chest may become flushed for a period of seconds to 2 to 3 minutes. A strong pilomotor reaction and erection of the nipple may be observed. After the sudden initial flexion movement, the lower extremities go into rigid extension; the upper extremities either into abduction, adduction, flexion, or extension; the hands in a tetanic position or clenched into a fist with the thumb often thrust between the second and third fingers.

"At 30 seconds the current is abruptly reduced to 60 to 90 milliamperes. Secondary currents have varied from 40 milliamperes, in one case, to 90 milliamperes, although in most cases they were about 80 milliamperes. Almost invariably, clonic twitches replace the tonic contraction and last for a period of 0 to 48 seconds, usually about 20 seconds. Respiration begins 30 to 70 seconds after the treatment is begun and is usually quite labored with evident flaring of the ribs. If the patient has received a large dose of barbiturate medication before treatment, or the initial current is too low, no clonic movements may appear, and respiration may begin almost immediately after the current is reduced to the secondary low level. When clonic movements occur, respiration generally begins immediately after they are terminated. After the first gasp, the airway is passed, the tongue blades removed, and catheters leading to a suction apparatus are placed in the mouth (one catheter is fixed in the airway, the other placed under the tongue). It is only occasionally necessary to use artificial respiration if breathing is difficult. The carbogen mask is placed over the nose and the mouth and carbogen is supplied at an approximate rate of 12 to 15 liters per minute. Cyanosis occasionally persists into or through the second and third minute of treatment, but usually subsides before that time.

"When respiration is well established, usually during the beginning of the second minute of treatment, the current is increased at the rate of 5 milliamperes every 15 to 30 seconds, depending on the character of the patient's respiration. Secondary currents have been raised from 40 milliamperes at 30 seconds (usually about 80 milliamperes) to as high as 150 milliamperes. When stridor occurs, the current is held at that level or slightly below it; when it recedes it may be raised. Generally the current is not raised beyond a 120 milliampere level, although the range in our experience has been 85 milliamperes to 150 milliamperes. When electronarcosis has gone on 5 minutes, usually no further attempts to raise the current are made, although we have made exception to this rule, on occasion raising the current in the last 2 minutes of treatment without ill effect to as high as 150 milliamperes.

"Patients vary in their reaction after respiration begins. The patient is quiet and relaxed for a few seconds after respiration begins, but spontaneous movements may begin shortly after the onset of respiration. If restless, semi-intentional movements occur early in treatment, the initial current or secondary current drop at 30 seconds is too low, and it is raised 10 milliamperes in the next treatment. Some patients display rolling movements of the body, walking movements of legs, hopping movements with one leg, opisthotonic movements, and these indicate the primary and secondary currents have been too low. The upper extremities usually are in flexor tone, the hands in carpopedal spasm, the lower extremities in extension, the feet in plantar flexion. Forced grasping occasionally occurs and is an indication for increase in current. Clonic movements later in the course of treatment are indications to lower the current. Intermittent clonic dorsiflexion of the big toe is commonly seen. However, no convulsion has occurred during the course of treatment unless the reaction during the first minute of treatment is regarded as such.

"Symptoms indicative of stimulation of the autonomic nervous system are observed in the excess salivation, lacrimation, pilomotor reaction, perspiration, erection of the nipple, slowing of the heart rate during first minute of treatment, tachycardia during the latter part; and the rise in blood pressure. Not every patient shows all these signs, however; nor are they seen in stereotyped fashion in the same patient with successive treatments. Enuresis occasionally occurs and ejaculation is occasionally observed.

"Treatments are discontinued after 7 minutes, although a few were discontinued after 2 to 4 minutes because of respiratory distress, or after 2 to 6 minutes because the electrodes were moved from position during the restless movements of the patients. A few treatments were extended as long as 15 minutes, with no untoward effects and no unusual therapeutic effect, and it was felt it could be safely extended much beyond this."

Estes and Cleckley [11] described results in 110 psychiatric patients treated with electronarcosis and listed complications including laryngospasm, cyanosis, cardiac arrhythmias, sore throat, dental complications, and thermal burns at the site of electrode application. One of the cases of cyanosis occurred when the patient bit a worn airway in half.

During the period 1942 to 1950, the psychiatric literature contained comparisons of electronarcosis and ECT. Gradually the opinion developed that electronarcosis offered no great therapeutic advantage over ECT. In addition, the additional hazards imposed by electronarcosis necessitated the presence of personnel competent to manage a mechanically obstructed airway, remove secretions, and monitor a disorganized cardiovascular system for a longer time for each treatment. Electroconvulsive therapy was preferred because of its relative simplicity in state institutions where large numbers of patients were treated.

Renewed interest in electronarcosis was shown in the anesthesia literature in 1954, when Knutson [19] published a preliminary study in ANESTHESIOLOGY. Using dogs, he found that an alternating current of 700 cycles per second through a constant-current amplifier could produce a form of narcosis with the lowest incidence of convulsive phenomena. It is Knutson's original contribution that this frequency offered promise as a means for electrical anesthesia. Currents of 25 to 80 milliamperes were used, with frequencies from 700 to 1500 cycles per second. Complicating factors included respiratory obstruction, tonic spasms, and cardiac irregularities. These were treated with *d*-tubocurarine, endotracheal intubation, intravenous pentobarbital, and atropine. In 1956, Knutson *et al.*[21] reported on the use of electrical current as an anesthetic agent in man as well as additional studies in dogs. Five patients in a mental hospital were studied. No surgery was performed. Drugs and techniques used to control the complications of electronarcosis included endotracheal intubation, controlled respiration, gallamine, edrophonium, atropine, and hexamethonium. One of Knutson's final paragraphs is reminiscent of Leduc and may serve to caution and to challenge the investigator in this field:

"Because of the seriousness of the cardiovascular complications in man (hypertension, cardiac irregularities, and tachycardia), we have discontinued our electronarcosis investigations in human beings. This is not to say, however, that we believe electrical anesthesia to be impossible of achievement, for in our work we have investigated only one more frequency (700 cycles per second) in man. It may well be that a higher frequency, or a different wave form, or a different combination of the variables of current, potential, and frequency, will produce a satisfactory narcosis without the frightening side effects. In order to investigate the problem logically, though, the work should be accomplished with man as the subject, since there is a marked difference in the reaction of electrical current among different species. Human volunteers who would be able to report accurately their experience during the narcosis would be the most valuable subjects."

The mechanism of electronarcosis has been considered by several authors. Earlier authors who worked with direct current tended to regard electricity as a depressant. van Harrevald and later workers ascribed the narcotic effect to a stimulant action of the electric current. Alpers and Madow [2] reported on changes in the brain associated with electronarcosis, and Karliner [19] has reviewed some of the complications of electric shock treatment. The flickering lights seen when electricity is passed through the head have been ascribed to stimulation of the retina and not the brain by Barnett.[4] Although the earlier work in 1936 of Burge [6] is not concerned with electrical anesthesia, his paper explaining the action of volatile anesthetics in terms of reversal of normal electrical polarities in the nervous system deserves mention. Burge found that the cerebral cortex of the awake animal was negative with respect to the sciatic nerve, but the polarity was reversed by ether, chloroform, nitrous oxide, ethylene, ethyl alcohol, pentobarbital, morphine, carbon dioxide, hemorrhage, or asphyxia. An unanesthetized goldfish in an electrically charged tank oriented itself with its head toward the positive electrode, but reversed its position after anesthetization with ether.

In 1941, Burge [7] repeated his electrical measurements, using spinal nerve roots in etherized dogs, and found that the anterior root was electronegative in deep anesthesia and the posterior root negative in light anesthesia. Although the currents were small (0.06 to 0.09 microampere), they were reproducible in a series of 16 dogs. An attempt to produce anesthesia in a frog by means of an electrostatic machine, with no electrode contact, produced a state in which the frog "appeared to be anesthetized. . . . Upon removal of the frog from the sphere of influence of the static charge it soon became irritable and active again."

Knutson's technique was used by Hardy and his associates [14, 15] as part of their studies on catechol-amine metabolism and other metabolic changes during surgery. Electrical anesthesia was found to cause a greater elevation of circulating catechol amines than ether, barbiturate, or local anesthesia.

A short abstract of work done in Russia by Anan'ev *et al.*[3] appeared in ANESTHESIOLOGY in 1959. Through the suggestion of Volpitto, the article was translated and published in ANESTHESIOLOGY 21: 1960.[3] Anan'ev used a combination of constant direct current with a superimposed square wave and reported satisfactory surgical anesthesia in dogs and also mentioned an "appendical revision" in a human patient which had been performed under electrical anesthesia in 1948 by Gilyarovskiy *et al.*[13] No further clinical information was given. The enthusiastic nature of the report prompted the reviewer to write to Dr. Anan'ev for a circuit diagram. The answer to the request was that a diagram could not be supplied, since the apparatus was still in a developmental state.

Smith and Volpitto [32, 33] had an apparatus constructed which produced the current described by Anan'ev and had varying degrees of success and complications (laryngospasm, salivation, burns) in a series of dogs. No human work was done. Improved electrodes were devised to secure better skin contact and minimize the incidence of burns.[33]

In 1961, Hardy, Fabian, and Turner [16] reported on the use of electrical anesthesia in two patients. Endotracheal intubation was done in one case after topical anesthesia and succinylcholine and in the other after thiamylal and succinylcholine. Electricity was applied to the first patient after "mild tranquility was achieved with thiamylal." Relaxation was secured by means of succinylcholine, and respirations were assisted or controlled. A systolic blood pressure rise from 130 to 180 mm. of mercury was noted, as well as excessive salivation. Recovery was rapid and the postoperative course following biopsy of an omental metastasis was uneventful.

The second patient had a simple mastectomy for carcinoma. An endotrancheal tube was inserted as described, and succinylcholine used during the procedure to prevent reaction on the endotracheal tube. Spontaneous respiration returned midway through the operation, and later the patient began to move her legs. After the current was increased from 45 to 55 milliamperes, all movements ceased. Excessive salivation and rapid recovery were again noted. In the presence of barbiturates, muscle relaxants, and controlled ventilation, the effect of the electricity is difficult to evaluate.

In a search for a more suitable wave form which might have fewer of the undesirable features of previously studied currents, Van Poznak and Artusio [40] applied sine, square, and triangular waves to the heads of unmedicated dogs. They produced lack of reaction to cutaneous stimuli but were unable to reduce undesirable effects such as salivation, laryngospasm, cardiac arrhythmias, cyanosis, and muscular twitching. Using electrodes securely applied to the skin as personally suggested by Smith, they were able to reduce but not eliminate the skin burns. This has remained one of the major problems in the study of electronarcosis regardless of the current employed.

TABLE 1. Summary of Parameters Examined by Various Investigators

Investigator	Year	Type of Current Used
Mach[26]	1875	Constant direct current.
Leduc[22]	1903	Interrupted direct current, 100 pulses per second, 10 millisecond pulse duration.
von Neergard[41]	1922	Leduc's technique.
Ivy and Barry[17]	1932	Interrupted direct current 6,000, 9,000, 9,8000 cycles per second, 1/10 and 3/10 on. Voltages from 4 to 110.
van Harreveld and Kok[38]	1934	Alternating current 50 cycles per second, 0 to 220 volts, 30 to 300 milliamperes.
Silver and Gerard[31]	1941	Constant direct current.
van Harreveld *et al.*[39]	1942	Alternating current 50 to 100 cycles per second.
Bowman and Simon[5]	1948	Alternating current 60 cycles per second.
Estes and Cleckley[11]	1950	Alternating current 60 cycles per second.
Knutson[19]	1954	Alternating current 700 cycles per second to 1,500 cycles per second, at 25 to 80 milliamperes.
Anan'ev[3]	1957	Interrupted direct current 100 pulses per second, pulse duration 1 to 1.4 millisecond, plus a constant direct current component. Average current 7 to 10 milliamperes, voltage 35 to 40.
Hardy *et al.*[14,15,16]	1961	As described by Knutson.
Smith *et al.*[32,33]	1961	As described by Anan'ev, *et al.*
Van Poznak and Artusio[40]	1962	Frequency 1 cycle per second to 10,000 cycles per second, square, sine and triangular waves. Variable pulse width for square waves.

The increased current needed for electronarcosis in man compared to the dog may be a species difference or may be related to factors such as electrode placement, thickness of skull, and size of brain. No neurologic sequelae have been noted by Hardy *et al.*[16] in their patients or by Smith *et al.*,[33] who performed EEG and microscopic studies on dog brains. In order to avoid painful stimuli, a gradual introduction of current was required for unmedicated dogs studied by Smith *et al.*[33] Barbiturates and succinylcholine had been used in the patients described by Hardy *et al.*,[16] making it difficult to evaluate the effect the alternating current would have had if used alone. Knutson *et al.*[21] reported distinctly unpleasant sensations from their series of five mental patients, who received no barbiturate prior to the application of the electric current. Rapid recovery was noted by Hardy *et al.*,[16] with a post-electronarcosis analgesic state.

Electrical anesthesia thus remains much as it was 60 years ago when Leduc described it—challenging but elusive. The present review is meant to provide a historical basis, a caution, and a challenge for the workers who will eventually present electrical anesthesia as a clinically-practical technique to our profession.

Electrical anesthesia is far from a clinical reality. It may become part of a technique in which electricity is used as one component of a type of balanced anesthesia utilizing physical as well as chemical forces. The higher frequencies and more complex wave forms have yet to be investigated. The frequencies investigated to date may be but carrier frequencies which will require a suitable type of modulation—amplitude, frequency, or phase—before they can become useful for production of electrical anesthesia. Electromagnetic fields of various types should be investigated. These may be able to induce the necessary physiologic changes deep within the brain while avoiding the problems of skin electrodes, burns, and excessive cortical stimulation. Other physical modalities, such as pulsed ultrasonics, are under consideration. Each of these physical forces will bring its own complications and hazards. However, the controllability of physical forces, and the absence of a drug which must be excreted or detoxified, make this general approach to anesthesia worth pursuing on a research basis.

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EPIDURAL BLOCK Umbilical artery and vein oxygen capacity, saturation, and content were studied in a series of infants delivered by elective cesarean section using both general and epidural anesthesia. These results were compared with those obtained in a series of infants delivered vaginally. The fetal umbilical-vein oxygen saturation and content was lower after delivery by cesarean section than after vaginal delivery, and was markedly lower with epidural than with general anesthesia. With epidural anesthesia, there was an increased coefficient of fetal oxygen utilization, implying reduced oxygen tension in the fetal tissues. (*Low, J. A.: The Effect of Cesarean Section and Epidural Anesthesia upon the Mechanism of Fetal Oxygenation, Obstet. Gynec. 20: 363 (Sept.) 1962.*)

LEGAL CONSENT When consent for a life-saving procedure is denied a child by a parent or guardian, it is the responsibility of the physician to notify the proper legal authority. Having reviewed the evidence, the court may award custody of the child to an authority, who may authorize any necessary treatment. Where time does not permit prevention of gross harm or death by such legal procedure, opinion is divided as to the action to be taken by the physician. One point of view is that the physician is never justified in taking the law into his own hands. Also, if present laws are not adequate, it is the duty of the constituted government to change the law. The other point of view is that no law can cover all eventualities. If the normal legal process is incapable of functioning in time to preserve life or prevent serious harm to a child, the physician has a moral obligation to prevent an unnecessary death. The first position is legally safe and secure. The physician takes no risk except perhaps with his own conscience. The second position is morally sound but legally assailable. The physician may by his action put his entire future at stake. Yet men of conviction from the time of Socrates have had the courage to stand above the law when deep moral issues are involved. (*Chute, A. L.: Blood Transfusion without Consent, Canad. Med. Ass. J. 87: 222 (Aug. 4) 1962.*)