Electronarcosis—A Progress Report

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In the search for safe anesthesia produced by the application of electrical current, the true milestones are relatively few. The first was the discovery by Mach [1] that direct current would render a fish insensible to pain. The second was the conclusion by van Harreveld [2] that the production of electronarcosis in mammals required rapid, rhythmic, repetitive stimuli to the brain.

Between these two milestones there was a great deal of time and energy expended in trying to produce electronarcosis by the use of direct current. Interrupted direct current, with a square wave of 100 cps and duration of 1 to 2 ms. was tried by Leduc [3] and his contemporaries, and simple direct current was tried by Silver [4]. Leduc's work failed because the direct current wave produced cardiac arrhythmias, hypertension, convulsions, apnea, and poor analgesia; it was too hazardous for safe use. A student of Leduc's employed a modification of his method to produce regional anesthesia for extremity surgery in Hartford, Connecticut in 1910 [5], but never succeeded in producing safe general anesthesia with the method.

Silver reported that he had produced spinal anesthesia in animals by running simple direct current between electrodes in the cisterna and the lumbar subarachnoid space. In frogs and rabbits direct current was found to be capable of producing a trance-like state which permitted surgery to be performed without reactions suggesting pain perception.

The third, and most significant milestone was the discovery by Anan'ev [6] that a combination of alternating current and direct current produced safe, effective anesthesia in dogs. Before this discovery, sinusoidal alternating current at 60 cps had been tried by van Harreveld and sinusoidal alternating current at 700 cps had been tried by Knutson [7, 8] and by Hardy [9]. It became apparent that simple alternating current was too dangerous to use for electronarcosis; the cardiovascular changes were too severe, and the margin between electronarcosis and convulsions was too narrow. Anan'ev, noting that direct current was relatively safe but usually ineffective in large mammals and that alternating current was relatively effective but dangerous, combined them in an attempt to derive the best from both forms of current.

As a result of Anan'ev's work, we can at the present time, by the application of electric current, produce (without the aid of any drugs), successful, safe anesthesia in dogs and Rhesus monkeys. In this statement, the expression "successful" means that the anesthesia is profound enough to make abdominal surgery possible. The test animals undergoing surgery under electronarcosis are insensitive to the most severe stimuli. The relaxation is short of optimal; dogs tend to breathe slowly and deeply, under electronarcosis, with forceful expiration involving the abdominal musculature, and the degree of relaxation produced would be inadequate for high abdominal surgery in human beings. If the dog's temperature rises, for any reason, panting results and the "flutter" effect on the diaphragm is a nuisance in high abdominal surgery on the dog.

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Despite these facts, the anesthesia produced by the application of electrical current is successful. The level of anesthesia in dogs corresponds, to the best of our ability to interpret it, to the third plane of the first stage as described by Artusio [*10*]. Analgesia is present to a remarkable degree. A dog, while being operated upon under this form of anesthesia, may respond to petting and coaxing by wagging its tail, just as the patient undergoing surgery under ether analgesia (I-3) will answer questions and be aware of no pain. In the Rhesus monkey, the level of anesthesia appears to be deeper, corresponding to the upper first plane of the third stage.

Earlier, the word "safe" was used to describe the form of anesthesia produced by electrical current. Safe anesthesia is anesthesia which is reversible and has no deleterious effects on the subject's vital functions and structures.

In dogs the anesthesia is instantly reversible. When the current is cut off the dog wakens instantly and when it is placed on the floor it walks about normally and acts as it did before electronarcosis was induced. There appears to be no change in "personality"; the dog which was friendly and happy before electronarcosis is the same afterward. This rapid recovery obtains even after eight hours of electronarcosis.

The Rhesus or Macaque monkey requires from ten to twenty seconds to regain full consciousness. On a few occasions, the time required to catch the monkey, before electronarcosis, was noted and compared with the time required after electronarcosis. After one hour of electronarcosis it was found that the animal was just as hard to get into the net as before; it was just as active and agile and determined, but after electronarcosis it tired in five minutes and was easily caught.

No deleterious effects on vital functions and structures are noted when the technic is properly managed. The areas studied have been the brain [*11*], the cardiovascular system, and the respiratory system. The electroencephalograph cannot be used because to date, no effective screening device has been found to permit electroencephalographic tracings to be made while the subject is receiving the form of electrical current we employ. Pre- and postelectronarcosis electroencephalographic tracings have revealed no significant change. Histologic studies of the brains of animals which had undergone several hours of electronarcosis revealed no evidence of injury or edema. Wood's light examination of the brains of animals which had received IV Fluorescin dye at the end of long periods of electronarcosis revealed no evidence of a breach of the blood-brain barrier by the current, at least to the molecules of the dye used. Studies are underway at present in dogs to determine the effect of electronarcosis on learned acts and the learning rate.

The studies on the cardiovascular effects of electronarcosis have been simple ones. Intra-arterial blood pressures and pulse rates have been observed as have been clinical factors, such as blood color, tissue perfusion and capillary filling. The blood pressure rises when and if the animal struggles, but only then, and stays at the pre-electronarcosis level throughout the period of electronarcosis. The pulse rate slows concomitantly with the slow forceful expiration which is commonly seen in electronarcosis. Rates as low as 68 have been observed in dogs, but 80 is the average pulse rate. There has been no evidence of poor perfusion in any tissue examined to date.

The studies on the respiratory functions have been simple ones. Dogs were intubated awake with the help of topical anesthetic agents, and then connected to a spirometer for thirty to sixty minutes for base line studies of rate, tidal volume and minute volume. The animals were then subjected to electronarcosis and the same observations were made. In a small series, the rate slowed, the tidal volume increased and the minute volume increased roughly 20 per cent over the resting level. P_aO_2 and P_aCO_2 and pH studies have yet to be performed.

As stated earlier, successful electronarcosis dates back only to the publications of Anan'ev in 1951. He employed simple direct current plus a square wave of alternating current origin. This wave had a duration of 1 ms. and a frequency of 100 cps. In this pattern he adhered to the concept of van Harreveld [*2*] that electronarcosis resulted from rapid, rhythmic repetitive stimulation of the brain, but he combined the direct and alternating current for a new concept. Leduc [*3*], at the turn of the century, used square waves of direct current origin at 100 cps of 1 to 2 ms. duration and produced, in dogs, convulsions, apnea and severe hypertension and arrhythmias. Anan'ev in 1957 used almost the identical pattern and achieved good, safe anesthesia. The difference

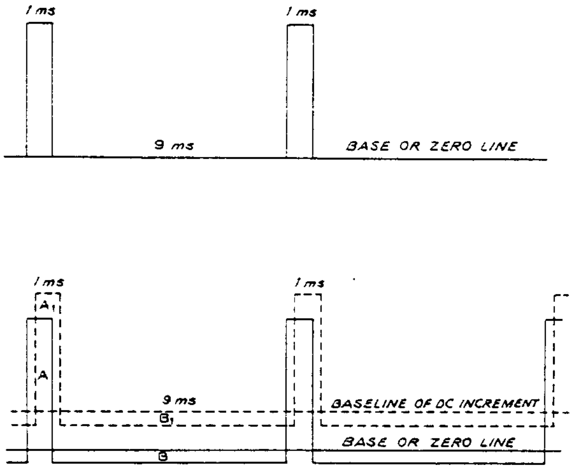

Fig. 1. The upper drawing illustrates: The square wave of Leduc which returns to the base line. The square wave is of DC origin. The lower drawing illustrates: The square wave of Anan'ev. It never reaches the base or zero line. The square wave is of AC origin, so A area = B area as A, area equals B, area. In each pattern the wave is 1 ms. duration; the frequency 100 cps.

between the two methods is minute, but of critical significance. The square wave of Leduc returned to the base line; the square wave of Anan'ev does not. In the method of Anan'ev the direct current is started first, and the alternating current is added and is kept well above the base or zero line. The wave form is observed on an oscilloscope with a reliable base line. As alternating current is increased, the negative phase moves downward but direct current is added so that the negative phase of the alternating current wave never reaches the base line. If it does so, the animal subject reacts violently and may convulse. This convulsiogenic tendency of raw alternating current is reported by all workers who have tried it for the production of electronarcosis. The accompanying drawing (Fig. 1) illustrates the principle of Anan'ev compared with that of Leduc.

We employ a modification of Anan'ev's idea. The generator, the circuit of which is pictured here (Fig. 2), produces a square wave of alternating current and continuous direct current. Since the square wave is from AC, the positive and negative components are equal and opposite. The generator is capable of producing many frequencies but all of our work has been done with a frequency of 100 cps or 1 every 10 ms., and a square wave duration of 2 ms. instead of 1 ms. as advocated by Anan'ev.

The meters we use to measure current, measure the average "positive" current, instead of the peak current, and in a 1 ms. wave repeated at 100 cps, the peak is 9 times the average whereas in a 2 ms. wave, the peak is only 4 times the average. We thus accomplish electronarcosis without the violent reaction noted when a 1 ms. wave is used. The maximum "positive" amperage at any one moment is the sum of the direct current plus the peak of the alternating current wave. We routinely start with 20 ma. direct current and add the alternating current to affect. After each increment of 1 ma. of direct current, it is necessary to stop the motor driven potentiometer which adds the increments, so that analgesia may be tested for. Electronarcosis may be present at 20 ma. direct current and 4 ma. alternating current but in some dogs it has been necessary to use as much as 40 ma. alternating current and 30 ma. direct current for the desired effect. To date no reason has been found for the variation in requirements between animals. A given animal has a more or less constant requirement of current to achieve electronarcosis satisfactorily for a given surgical procedure.

A discussion of voltage is difficult. We employ a 400 ohm resistance for a dummy load in our electronarcosis generator and do so because the average dog head appears to offer approximately that much resistance to the current we put through it. However, we have no real idea whether the 400 ohms resistance of the dog head is due to the skin, to bone, the electrolytes of the fluids in the head, or to what it is due. A rough approximation, for practical purposes, is all we have. The voltages required are best measured on the oscilloscope, and vary from animal to animal, with the same current input.

The electrode placement pattern recommended by Anan'ev is with the cathode on the occiput and the anode at the eyes, in the dog. We have modified this pattern, placing the cathode on the vertex and the anode in the roof of the mouth. The change was made because the current applied to the occiput evoked contraction of the neck muscles with resultant shortening of the neck and obstruction to the airway. When the cathode was moved to the vertex leaving the anode at the eye level, electronarcosis could not be produced. An examination of the dog head sectioned in the midsaggital plane revealed that this pattern of electrode placement sent current over the top of the brain; there was no brain mass between

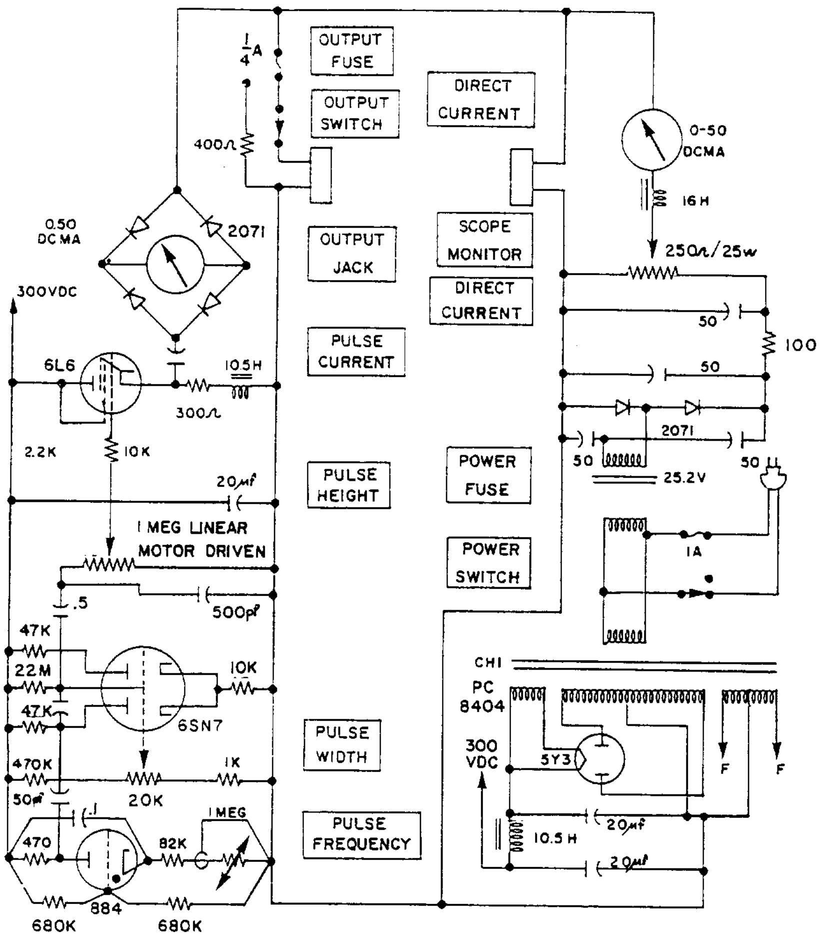

Fig. 2.

the electrodes. Moving the anode to the roof of the mouth, as far back as practical, again made electronarcosis possible, and electronarcosis could be produced with no more current than had been required by the original placement.

Leduc [3], mentioned previously, was one of the few pioneers in electronarcosis work who employed the sagittal orientation. Most of the other workers have employed bitemporal placement. This pattern is not too successful because the electrodes overlie the motor cortex and the current elicits a great deal of motor activity, even up to convulsive levels. Anyone who tries to find a satisfactory means of holding electrodes on a dog's head will find very quickly why the bitemporal arrangement has been preferred. The electrodes can be tied securely in place in a few minutes. The means of holding saggitally oriented electrodes in place on an active dog are difficult to imagine, and harder yet to create. A completely successful means, satisfactory in all details, has yet to be found.

The pattern of current application described by Anan'ev reflected his work on electrosleep. He advocated a fifteen minute period of electrical sleep in each animal, accomplished by 0.5 to 0.9 ma. He followed this by a slow build-up of current to about 10 ma. over a twenty minute period. This thirty-five minute induction period, in our hands, was a mistake; we simply had to fight the dog for the entire period. We finally settled on a 20 ma. direct current input in one or two seconds followed by alternating current added at about 1 ma. per fifteen seconds. Thus an animal requiring 10 ma. AC is in electronarcosis in under three minutes, as we handle the problem. Struggling is largely ended by the time the animal is receiving 20 ma. direct current and 5 ma. alternating current. The induction is uncomfortable. A dog quietly undergoing abdominal surgery will whine if an increment of alternating current is added to compensate for a fall in current secondary to a rise in resistance in the electrodes.

As this last statement implies, a rise in resistance in the system results in a fall in amperage, because the generator operates on a fixed voltage. Anan'ev stated "In the apparatus for electronarcosis the subject is hooked into the cathode circuit of the output tubes, which provide constancy in the voltage." The generators we have built employ this principle.

The electrodes we employ are metal covered with vinyl plastic sponge saturated with supersaturated saline solution. The direct current will polarize most metal electrodes and this necessitates additional voltage to hold a given level of amperage input. Solid metal electrodes, even at the low amperages employed, cause severe burns due to the high current density. The wet sponges prevent these burns.

Very little of our experimental work has been what could be described as well controlled. It has been a pattern of trial and error with observation and recording of the results. The ultimate objective, of course, is clinical use. Before this can be achieved, full studies with adequate control subjects must be made, first in dogs, next in monkeys and finally in chimpanzees. In the past work with electronarcosis it seems to have been the concept that if man is to benefit man must be the experimental animal. Our feeling on this point is that the methods used now are crude and need a great deal of refinement before human beings can be used as subjects. It may be that cause will be found to abandon the procedure before trying it on human beings, although to date, nothing has been found that would point that way.

Controlled studies in this work are complicated by some very awkward developments. The problem is whether to test a given effect on a large, significant number of animals, or on a small group of animals, repeatedly. This decision is affected by several factors.

One of these problems is that of the comparison of unknowns and "known" effects. For example, a given dog is in a surgical plane of anesthesia with 20 ma. direct current and 10 ma. alternating current put in at 100 cps with a 2 ms. square wave. If sinusoidal waves, or longer or shorter waves, or more or less frequent waves are employed, this animal may not be in surgical anesthesia with 20 ma. direct current and 10 ma. alternating current. The question is: why not? We have found that very minute changes in the characteristics of the electrical input can produce profound physiologic changes in the test animals. For example, the extent of the postelectronarcosis analgesia seems to be related as much to the "noise" in the circuit output as to the wave form. One of our generators could be depended upon routinely to produce a good solid postelectronarcosis analgesia. Another, after having some of the "noise" (detected on an oscilloscope with a very fast rise-time) removed, could not be depended upon to produce this phenomenon. Both instruments are producing a "square" wave of 2 ms. duration and frequency of 100 cps, as seen on an oscilloscope with a "standard" rise time. It may be that a controlled study of any single characteristic or change in that characteristic, as current is added, would require that the same instrument be used throughout, and that the results could not be duplicated with another generator.

Another problem is best described as "technical difficulties." We recently had a complication that invalidated an entire day's work on respiration. The test animal's tongue became cyanotic early in the study, and persisted this way despite every effort to provide airway. It was learned eventually that poor electrode placement was permitting current "leakage" to the dog's tongue, resulting in spasm and cyanosis of the tongue on a strictly local basis.

Another such "accident" occurred when a wet dog was subjected to electronarcosis for the fourth time. The requirements had been 20 ma. direct current and 12 to 13 ma. alternating current. When the animal was wet, having been out in a rain, it could not be anesthetized with electrical current. Presumably there was too much dissemination of current over the wet body surface and too little concentration of current passing through the brain.

Summary

Since electronarcosis in the form described is still in the crude trial and error stage, good controlled studies are going to have to be "hedged" well, with a full circuit of the generator, exact information on electrode composition and placement, specific descriptions of the pattern of current input, and all other minutae which might be important to anyone wishing to duplicate the work.

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