ELECTRONARCOSIS *

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THE subject of this research and experimentation is the effects of linear interrupted currents on vertebrate animals, with particular reference to the production of anesthesia, analgesia, and sleep.

Stephane Leduc (1), in 1902, with the aid of D'Arsonval, described a method whereby, under certain well determined conditions of voltage and current, a series of states could be induced ranging from simple muscular excitation to generalized epilepsy and electrocution. Well before these last two phases were reached, however, an electrical sleep occurred, with both motor and sensory inhibition. Zimmern (3), in 1903, was unable to duplicate these experiments and stated "Electrical sleep does not exist; the inhibitions brought on by the currents of Leduc ought to be interpreted as accidents of the consecutive series and not as true sleep." Hertz, after experiments on animals and man, came to the conclusion that "General anesthesia, or more exactly electrical sleep, by the application of the currents of Leduc is irrealizable, the supposed anesthesia being in fact only contractures having a veritable dissociation of sensibility, leaving intact the tactile sensibility by suppressing the muscular reflex action." Foveau de Courmelles (5) decided that loss of consciousness has "not been definitely proven to take place during electrical anesthesia," but also states that "it ought to be possible, it is possible, but it is yet to be found to have constancy, to be easy to repeat, so as to work for the veterinarian or the surgeon."

More recently, Y. Hirata (4), in a highly technical and admirable work, experimented with various types of currents on frogs and fish. He used the reflex movement as the only reliable criterion of electronarcosis, much more so than the corneal reaction or muscular tension tests. He concluded that "if the cathode is placed on the head and the anode on the hip, the best results are obtained with the smallest voltage, the electronarcosis is stronger. Smallest influence is seen when both electrodes are on the head. During the effect of electronarcosis, the oxygen consumption is strikingly reduced, but increased on coming out of coma. When high frequency or Tesla waves and currents are changed to those of lower frequency, there is some electronarcosis. The results of electronarcosis effects on the animals is different from

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that on them caused by the plain electric current." The effect of a positive electrostatic charge on the brain of the frog was found by Burge (10) and associates, to be "decreased irritability, anelectrotonus, unconsciousness and anesthesia."

From a purely theoretical standpoint, electronarcosis may be predicated on the basis that there is a definite measurable relation between the transmitted nerve impulse and the action current which accompanies it. That the entire body, as well as the nervous system, operates on a colloidal, ionic, and necessarily electrical basis is borne out by both theory and experiment (6, 7, 10, 11). The galvanometer in the form of the electrocardiograph and the electroencephalograph proves there is a definite relation of the passage of electrons to the vital body function. Differences in potential have also been shown to exist between different parts of the nervous system, as in the work of Burge et al. (10), who found differences in voltage between the anterior and the posterior nerve roots of the anesthetized dog. This work lead to an hypothesis as to the cause of their previous findings (11) that the brain cortex of the conscious animal was electronegative, that the administration of anesthetics gradually decreased this negative potential to zero, and that on further increase in the depth of anesthesia, a reversal in polarity occurred. In deep surgical anesthesia, the brain cortex became electropositive. The electronegativity of the motor anterior roots of the deeply anesthetized dog is interpreted to indicate that more negative charges, or nerve impulses, were leaving the brain by the motor anterior roots than were coming to the brain by the sensory posterior roots. This resulted in a loss of negative charges, thereby causing the brain cortex to become electropositive in deep anesthesia. Conversely, in the conscious state more negative charges were coming to the brain by the sensory posterior roots than were leaving by the motor anterior roots. This resulted in a gain of negative charges and the cerebral cortex became electronegative. Upon death, these phenomena all cease and neutrality prevails. General anesthetics, like local anesthetics, apparently block sensory nerve fibers, and thus prevent the passage of negative charges, or nerve impulses, to the brain, while motor fibers are left unimpaired to conduct negative charges away from the brain (12). This blockage of the impulse of the sensory nerves alone is the prime and most important effect of anesthesia, and the motor nerves are blocked only when the cerebrum becomes electropositive, with resulting general anesthesia.

Motor nerves may be blocked only by exaggerated effect of the local anesthetic. Thus, in the induction of general anesthesia perfect results are obtained before cessation of motor function, and in the induction of local anesthesia they are obtained without loss of motor control.

In a simple galvanic circuit, the cathode has an irritant effect, attracts hydrogen and is a vasodilator; the anode is sedative, attracts oxygen and is a vasoconstrictor (9). These marked polar effects are not seen with primary faradic currents, are only slight with secondary faradic currents and have no true ionic properties. Secondary faradic currents may have a high voltage, up to 40,000 volts, but the amperage is usually not over 1 milliampere. The sinusoidal, or slow, medium, and rapid regular frequency currents, also have no polar effects and no electrolytic and ionic properties. From a physiologic standpoint, the voltage and frequency of the waves are important in their effects on muscle contraction, while the amperage is so slight as to have no effect. With this type of current, clonic muscular contractions take place at 5 to 20 per second; above 2000 per second, muscular contraction becomes tetanic and above 10,000, muscular contraction ceases.

The type of current employed in our experiments was an interrupted galvanic current, raised to maximum or reduced to zero instantaneously (fig. 1), as proved by observations with a cathode ray oscillo-

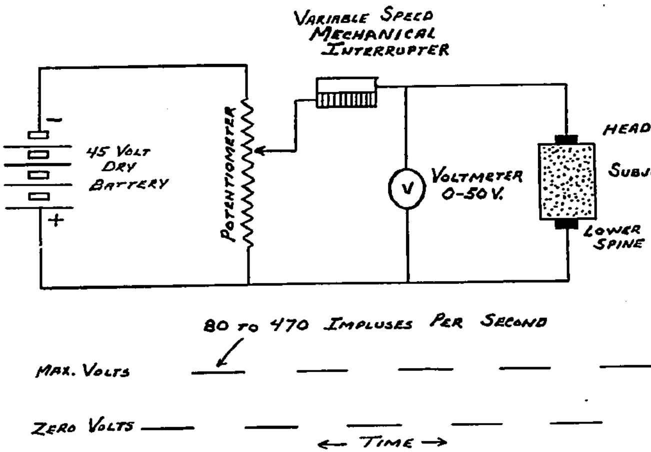


FIG. 1. Oscillogram of current produced by mechanical interrupter.

graph. This type of current derived from a mechanical interrupter is distinctive from that furnished by a thyratron, which produces a saw-tooth wave. The cathode of sheet lead, 3 by 4 inches, was wrapped in gauze moistened with 5 per cent sodium chloride solution and firmly attached to the previously shaved head of the animal. The anode is similarly placed on the back near the tail. The currents used in the experiments ranged from 80 to 470 interruptions per second, from 0 to 17 volts potential, at from 2 to 10 milliamperes current (fig. 1).

It was found that different animals produced comparable results physiologically, but often at different levels of interruptions and voltage. However, repeated experimentations have enabled us to draw certain conclusions as to the degree of relaxation or excitation produced by currents of varying voltage at interruptions as depicted in figure 2.

The general effect is that the animal is irritated by the gradual increase of voltage, the more rapid the period of induction up to the maximum voltage, the more irritation or muscular spasticity is produced. Fibrillary twitching and clonic contractures are common at between 3 and 7 volts, and considerable excitement may take place. As the

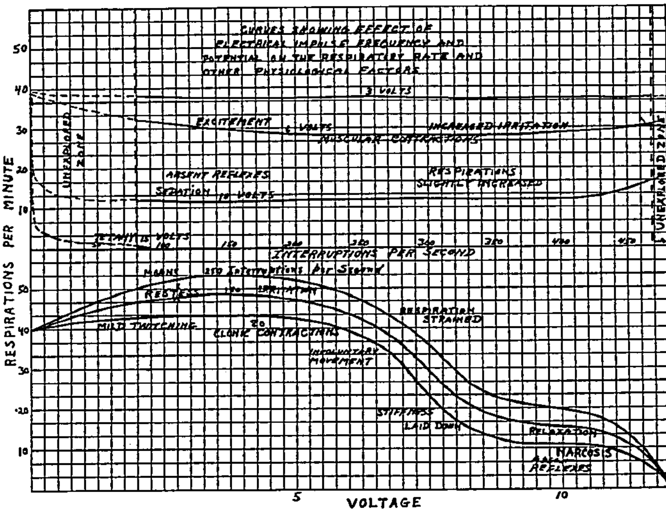


FIGURE 2.

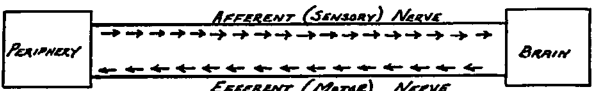
voltage is gradually increased beyond this point spasticity occurs, respirations are slow, deep, and labored, and if voltage is increased beyond the 10 to 17 voltage stage, the respiratory muscles become tetanic and the dog dies. However, if before the stage of tetanic contractions is reached, or immediately thereafter, the voltage is dropped back slightly, a stage is reached whereby the dog continues to breathe slowly and evenly, there are no reactions to painful stimuli, no reflex movements and no corneal reflexes, although the eyes may be open and staring. At this stage there is no muscular rigidity. In general, interruptions of lower frequency are more sedative than those of higher frequency, although this effect is not easily discerned in all cases. This stage is difficult to achieve because of the apparent concomitant effect on motor nerves, but once arrived at, is maintained with ease for periods of twenty minutes or longer. Upon removing the animal from the effect of the current, there is a period of hyperpnea but no evidence of pain, and the dog quickly returns to normal. Dogs which were watched for a period of several days thereafter showed no ill effects.

Some dogs did not go through the stage of relaxation, but had an exaggerated muscular response; in others the margin between the lethal voltage and the optimal voltage was very narrow. Many factors enter into the production of satisfactory results: the electrodes must be firmly attached, the cathode must be on the head, the voltage must be increased very slowly and the occurrence of tetany is a signal for immediate reduction in voltage if the animal is to live. In spite of this, one of the easiest ways to arrive at the optimal voltage is to increase to the point of tetany and then immediately drop the potential 1 or 2 volts. The results obtained are graphically illustrated in figure 2.

The passage of interrupted currents through the nerve paths, in particular of the brain and spinal cord, may interfere with the passage of the normal nerve impulses in a number of ways. It may interfere with the normal metabolism of the nerve tissue itself from which the energy for the normal nerve impulse is derived. It may interfere with the maintenance of continuous muscular tone for which the nervous activity consists of a series of distinct impulses (300 to 3000 per second). It may interfere by breaking through the resistance to "conduction" ordinarily found in the synapses of the reflex arcs. Theoretically, total inhibition of nerve activity could take place by keeping the nerve in the refractory period by stimuli closer together than 0.0025 second; however, in actual practice this does not seem feasible since the higher frequencies often had the more irritant effect. The effectiveness of the lower frequencies might mean a coincidence of waves with the normal Burges rhythm waves. A summation effect is also possible, of course, from continual stimuli after the refractory period of the nerve. In the same light, theoretically the impulses should be kept in the period between the refractory period and the super-response period, if possible, so as to get inhibition. Actually to what degree these factors enter is yet to be determined. In figure 3 is shown a possible explanation for the effects seen under electrical interrupted currents.

As normal flow of nerve impulses is toward the brain in the sensory nervous system and away from the brain in the motor nervous system, the introduction into this natural circuit of a stronger stream of negative electrical energy from the cathode on the brain to the anode at the spine will cause a reflux of the normal afferent impulses in the opposite direction, overcoming the normal valve action of the synapses and producing a total blockage of the afferent impulses. This in itself would constitute anesthesia. Unfortunately, at this time, as seen from figure 3, there is actually an equal effect upon the efferent system, with no adverse polarity of the reflex to contend with, and resulting in an increased motor effect. This was seen repeatedly in the experiments, and the excessive excitation of the muscular system was the adverse feature of the experiments. The point of optimal voltage was often, as formerly explained, quite close to the lethal voltage, a feature difficult to explain under our present knowledge of the facts, except to say that the sensory nerves apparently became blocked and the motor nerves refractory at this point.

We believe that this work indicates that linear interrupted currents produce physiologic changes constant enough to be predicted, that although the report of Leduc was over-optimistic, nevertheless our experimentation does not warrant the complete rejection and abandon-



Theoretical Electron Flow in the Nerves of a Normal Body.

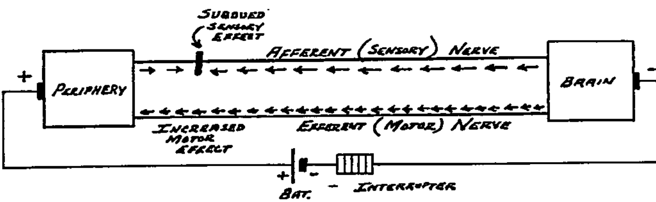


Fig. 3. Theoretical effect of an interrupted direct current upon the normal electron flow in nerves.

ment of later research workers. The subject carries such great implications that even the relatively meager success to date still opens the way for much improvement. Further experimentation is to be done at the higher frequencies and under many conditions. It appears that there are still factors to be determined before complete analysis of the results can be made.

In conclusion, it may be stated that the optimal results, with the currents employed, were obtained with 10 volts interrupted from 100 to 120 times per second, with very gradual induction and particular care required to avoid lethal potential.

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