Research Methods

Electronarcosis by Combination of Direct and Alternating Current

3. Electrodes and Electrode Holders

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In two previous publications [1, 2] progress was reported on efforts to produce electronarcosis by the application of a combination of direct and alternating currents, and Anan'ev [3] was credited with this "break-through" combination. In the summary of his work Anan'ev did not include information on electrode composition or the means he employed to hold the electrodes in place on the dog's head. These omissions have made it impossible to duplicate his work exactly.

The problem of current application does not seem complicated. All that is required to produce electronarcosis is to hook generator and animal together, and apply the current as advised. However, the problems involved in establishing effective connection have been formidable. Solid and mesh-metal surface electrodes, and solid subcutaneous, intramuscular and intraosseous electrodes were employed first and produced serious burns at the site of application, owing to high current density. Sponge electrodes saturated with an electrolyte solution were then tried in an attempt to eliminate burn. This innovation produced some improvements and some more problems. The increased contact area provided by the sponge reduced the current density per unit of surface and eliminated burns. The sponge is soft and is better tolerated, when it is in position, than metal electrodes. The sponge has a certain amount of "traction" and does not slip as easily as does solid metal if the test animal moves. If the electrode is tilted by movement, the sponge, compressed against the skin, tends to "roll," providing a large area of contact. This latter is highly important in maintaining continuous connection between the test animal and the generator.

On the other hand, troublesome problems associated with use of sponge contacts appeared. The sponge must be kept wet with electrolyte solution. If not, drying occurs consequent to evaporation and the formation of chemical compounds and gases at the surface of the metal electrode buried in the sponge. If the sponge dries even moderately, conduction is impaired and resistance rises. The generator has a fixed voltage output. If the resistance rises, the amperage falls. If amperage decreases, electronarcosis lightens. Correction can be made by increasing voltage but this is not without disadvantage and it is better to resaturate the sponge.

Conversely, if the sponge is too wet the solution spreads on the animal's head, the current input is spread over a wide area, and unnecessary and troublesome muscle activity is evoked. In our experience, it is not possible to produce electronarcosis in a wet dog, also because of diffusion of current.

The most severe problem is polarization of the metal electrodes by the direct current. If copper is employed for the metal electrode, the chemical reaction between the copper, water, and NaCl in the presence of direct current is very rapid and pronounced. If copper electrodes are used electronarcosis can be produced in a dog, but the rapid rise in resistance at the electrode surface necessitates the increase of voltage within a minute. The resistance rise persists and in a very short time, the capacity of the generator is reached, the narcosis "lightens" and the dog eventually wakens completely.

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When silver is employed for the electrode, the same results are obtained, but at a slower rate. The anesthetist must keep constant watch of the ammeters, and increase voltage to compensate for resistance. It must be understood that although the polarization is consequent to direct current action, the resistance affects both direct and alternating current.

The first part of this report concerns studies on polarization of electrodes of silver, silver chloride, gold, palladium and carbon.

Part 1—Electrodes

Methods

Electrodes were constructed of 1000 fine silver, silver chloride, 24 carat gold, pure palladium, and carbon. For each type of electrode the lead wires and supporting stem were silver-soldered to the back of the electrode and the electrode was mounted on a Plexiglas base, using plastic cement, so as to leave only the pure metal electrode-face in contact with the electrolyte solution in the sponge. The electrodes were set up in pairs as anode and cathode in a circuit including a 400 ohm resistor and a saline-saturated sponge.

Direct current, 20 or 30 milliamperes, was put through the system for varying periods of time. With a fixed voltage input, fall in milliamperage was construed as secondary to a rise in resistance in the system. The sponges were kept saturated to the dripping point, and the setup was so devised that solution that dripped did not "short" the system.

The sponge, very wet with supersaturated NaCl solution, presented about 500 ohms resistance. The sponge was $1 \times 1 \times 2$ inches; the 2 inch length was compressed between the electrodes to ¾-inch thickness. The solution itself, in a plastic container, with the test electrodes 1 inch apart, measured 500 ohms resistance. The tester employed a 1½ volt dry cell battery for the current source.

Results

Silver Anode–Silver Cathode–20 Milliampere DC. A 4 milliampere drop occurred in eight minutes. The anode was covered with a tight black layer of material which did not raise the resistance as measured by an electrician's volt-amp-ohm-meter. The cathode had surface deposits of greyish white, crystalline material, and the resistance rise over the surface of the electrode varied from zero to 200 ohms.

The electrodes were then reversed. In four minutes, the amperage dropped 4 milliamperes. The black residue on the former anode (now the cathode) was loose and amorphous, but thicker. No change was noted in resistance. The anode had a heavier incrustation of crystalline deposit with a resistance of 1,000 ohms.

Silver Anode–Carbon Cathode–20 Milliampere DC. Again, a 4 milliampere drop occurred in eight minutes. Resistance rise was all in the silver; there was no change in the carbon.

Carbon Anode–Silver Cathode–20 Milliampere DC. A 3 milliampere fall in two hours. No change was noted in the silver electrode. The carbon electrode resistance rose from 0 to 20 ohms.

Gold Anode–Gold Cathode–20 Milliampere DC. There was no change in six hours, in the amperage setting, and no change in resistance of the metal, to testing. This result was duplicated by running the test for two hours, three times.

Palladium Anode–Palladium Cathode–20 Milliampere. No change occurred in the milliamperage in 30 minutes. At the anode the sponge looked burned at the contact area. No change was detected in electrode resistance.

Thirty milliamperes for six hours gave the same results. The sponge began to dry out and the amperage fell 2 milliampere, but restoring the supply of electrolyte solution brought the current output back to the starting level.

Carbon Anode–Carbon Cathode–20 Milliampere. No change in current flow in four hours and no rise in resistance by individual electrodes, to test, was seen.

Silver Chloride Anode–Silver Chloride Cathode–30 Milliampere for 10 minutes. There was a fall in current, from the original setting, of 11 milliampere in ten minutes. Testing for resistance was difficult. The "probes" of the tester were sharp, and penetrated the thin layer of silver chloride, giving very low readings of resistance. If the probes were laid flat on the surface, the resistance in some areas was total; there was no current flow. In other

areas, resistance measured 1,000 and 2,000 ohms.

Discussion

The palladium, gold and carbon all gave highly satisfactory results; there was no significant fall in amperage secondary to a rise in resistance in the metal electrode. As a result of this work, palladium was chosen for general use in our work in electronarcosis and has proven to be satisfactory. Palladium is a tough, bright metal, easy to silver-solder, is firm in its structure and form, and is easy to work with. It can be cut with a cold chisel and can be hammered flat with a few light blows of a hammer.

The other substances were not selected for the following reasons. Gold is just as effective as an electrode, but it is twice as expensive, and very soft. It is tricky to silver-solder lead-wires to gold since its melting point is quite low. Carbon is satisfactory in performance, but it is, again, difficult to work with. Carbon from dry cell batteries was used, and it was necessary to depend on pressure contacts for the lead wires. Sealing the carbon into plastic holders was unsatisfactory. It was necessary to dissolve Plexiglas in a Plexiglas cement and pour the thickened material around the electrode to seal it. The cement appeared to penetrate the carbon, producing a fragile bond which had to be re-established four times in one day's use. Carbon was used as the other electrode in making the silver chloride electrodes which were tested. The thickly plated silver electrodes were placed in a normal saline solution for four hours. At the end of that time the carbon electrode appeared to be unchanged in any measurable function or dimension. The silver electrodes, of course, were coated with white silver chloride.

Part 2—Electrode Holder

As indicated previously, another omission in Anan'ev's report was the method he employed to hold the electrodes on the dog's head. In earlier reports we described the method wherein the oral electrode was tied into the roof of the mouth, and the vertex electrode was held in position by a nonconductive rubber hood secured at the back by the dog's collar, and at the front by the cords which held the oral electrodes in place.

The advantages of this method were few. It was easy to move the lower jaw and tongue and easy to intubate the dog's trachea. If the dog was left stretched out prone, the method was reasonably satisfactory.

The disadvantages were many. The tie about the upper jaw impaired circulation of the area rostral to the tie, and the nose and upper lips were severely swollen within four–six hours. The oral electrode was reasonably stable, but the vertex one was always a source of anxiety. It required a tight collar and a tight tie-down of the dog's head via the collar, and even then the dog could twist his neck in the collar and dislodge the vertex electrode. If the animal was turned to its side or back for the surgical procedure, the turning required a great deal of time and care, and was often unsuccessful. If the dog was tied supine before the electrodes were applied, it was necessary to construct a device so the dog's head could be tied *up* to a platform, to hold the vertex electrode in place.

These problems have been attacked by fixing rigid electrode holders to a rigid bony structure, the upper jaw. A cross member, padded on its under surface, is held tightly to the top of the nose, just anterior to the eyes, by wide hooks clamped onto the heavy back teeth of the upper jaw. The electrode holder is held in position by a bolt welded to this anchored cross-member. The electrode holder is a scissor type structure to facilitate application and equal pressure on both electrodes. A "fulcrum" to prevent pressure on the soft nose, and lateral guides to clamp the head complete the assembly. The holder depicted here is a prototype, and handmade, but has been successful in practical use. One disadvantage has been noted. It is difficult to intubate a dog's trachea with the holder in position. One precaution must be mentioned; the oral electrodes must not touch the metal tooth-clamps, or shortening will result, and electronarcosis cannot be produced.

The dog cannot twist in this holder, and can be placed in any position without losing electrode contact. Nose swelling has been elimi-nated.

The peculiar shape of the electrode holder is consequent to the shape of the dog's head, and makes the fulcrum depicted necessary to avoid injury to the soft part of the nose.

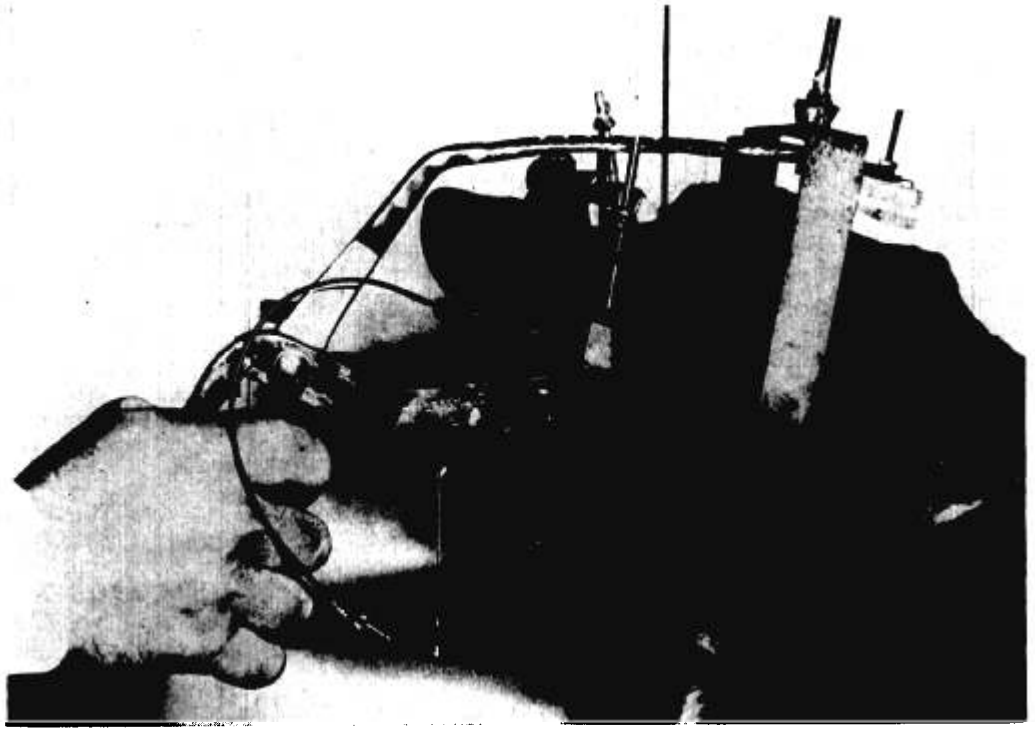

FIG. 1. A view of the electrode-holder in position on a 30-pound dog. The holder is modified from a plier-wrench 11 inches long. The vertex electrode holder measures 4 inches from axle to the angle, and 8 inches from the angle to the end. The oral electrode holder measures 2 inches from axle to the angle, and 5 inches beyond the angle. The lateral guides are 5 inches long, are adjustable, and clamp snugly against the head to avoid the effects of twisting movements. The tooth clamps are of light steel and are ½ inch wide. They are so-built as to catch and hold on the small projections on the back upper teeth. Tightening the wing-nuts holds the cross-member solidly in place. Padding of the ½ × 3 inches cross-member is essential, as is padding of the "fulcrum" which rides the nose rostral to the tooth-clamped cross-member, and prevents bruising of the soft nares. In the photograph, the hand hides the handle-clamp to hold the handles tightly together.

Despite its appearance, this electrode holder is well tolerated by the dogs; it does not produce pain. The pressure of the electrodes is not severe. The pressure on the top of the nose need not be severe; the hooks hold well on the back teeth, and only pressure enough to stabilize the apparatus through induction is required. Awake dogs which have undergone electronarcosis several times will lie quietly for an hour with the electrodes in place and show no distress.

The dog that is a subject for electronarcosis for the first time experiences three new procedures; it is tied down firmly, it has the electrodes fastened in place and it receives electrical current. Each of these is a new and frightening experience. A dog which is tied down and released several times gets over its fear and accepts the situation better with each repetition. The same holds true for the electrode application. Calmer dogs result if the electrodes are applied and removed a few times before electronarcosis is induced. This process of education or training for the dog requires an hour, and it is time well spent. The dog becomes accustomed to the procedure and to the handler's voice and hands. Then, when electronarcosis is begun, the only new factor is the current. The handler's voice and hands control much of the dog's panic during the induction. After the induction, the animal is narcotized and quiet.

The animals are handled as described because no drugs are employed for sedation or tranquilizing. The dog's natural fear and panic must be controlled if one is to avoid

wild inductions which result in torn-up equipment and exhausted personnel.

Summary

The tests indicate that electrodes composed of palladium, gold or carbon are superior to those made of silver, in the production and maintenance of electronarcosis in dogs. Palladium has been selected for routine work on electronarcosis. Also described is a rigid electrode holder for use on the dog. Its performance has been satisfactory in routine use.

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Ostwald Solubility Coefficients for Anesthetic Gases in Various Fluids and Tissues

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DURING the course of investigation into the solubility of halothane in blood and body tissues and its role in halothane uptake and distribution,[1] we had frequent occasion to refer to previously determined solubilities of other anesthetic gases. It became apparent, however, that no comprehensive table of solubility coefficients for anesthetic gases in various media at several temperatures existed in the literature.

As a consequence, extensive exploration of the literature on this subject permitted compilation of such a table for a number of anesthetic gases. The table is organized in a manner identical to that used in the *Handbook of Respiration* for oxygen and carbon dioxide.[2] All Bunsen coefficients have been corrected to Ostwald coefficients at the temperature of the experiment in degrees centigrade.[3]

We do not purport that this table contains all solubility coefficients which have been determined for the anesthetic gases listed. Several of the earliest investigators did not appreciate the need for equilibration between liquid and gas phase and hence their results are highly questionable and not perpetuated in this table. References to their work can be found in the International Critical Tables.[4] Solubility values for halothane are not included in this table since these have been tabulated in a previous paper.[1] Reprints of this table are available upon request.

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