ELECTRICAL ANESTHESIA produced by a combination of Direct and Alternating Current

Technical studies in the Macaque Monkey

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As a part of a continuing inquiry[1-7] into the possibility of developing electrical anesthesia into a safe clinical tool, 6 macaque monkeys were subjected to electrical current and the resulting anesthesia evaluated for adequacy and safety. Anesthesia was considered satisfactory if there was no response to opening the peritoneum and exerting traction on the renal pedicle. Measurements were made of heart rhythm and rate, blood pressure, pO_2, pCO_2, and pH, and determinations of serum glutamic oxalacetic transaminase (SGOT), and serum creatinine were made before and after anesthesia.

In studies on dogs, it had been ascertained that anesthesia produced by the application of direct current (DC) plus a square wave of alternating current (AC) or DC origin was both effective and safe, and the current patterns were thought to be reasonably specific. In the macaque, these and several other wave patterns were tried—as well as many different application patterns, electrode types, electrode compositions, wave durations, and wave frequencies. It appeared that the nature of the current pattern was relatively unimportant; anesthesia could be produced by several current and application patterns. What was important was the monkey's response to current, and the steps necessary to offset a violent response.

When dogs were re-evaluated in the light of these findings, it was found that there was more specificity in the need for DC plus a "spike" than was found in the monkey. However, some dogs could be anesthetized with almost any current or application pattern.

METHOD

Each monkey was strapped to an operating table as shown in figure 1. Using 1 per cent lidocaine without epinephrine for anesthesia, a femoral artery was exposed and cannulated with a nylon catheter connected to a Sanborn strain gauge and a Sanborn recorder. Blood pressure was recorded continuously. Baseline arterial blood gas samples for pO_2, pCO_2, and pH were drawn anaerobically. Venous blood was drawn for baseline SGOT content, blood glucose, creatinine, hematocrit, and white blood count. The current was then applied.

At the time electrical anesthesia was established and after 1 hour of electrical anesthesia, arterial and venous blood samples were drawn. The current was then shut off and the animal's wakening observed. The monkey was considered to be awake when it bit anything offered to it. Blood samples were drawn ½ hour after the animal was awake and the same group of tests performed.

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Twenty-four hour post electrical anesthesia tests were made for SGOT and creatinine.

When required, sponge electrodes were sewn with nylon sutures under local anesthesia to the vertex or occiput.

RESULTS

With every electrical application, even with simple DC, the animals held their breath and effectively performed a Valsalva maneuver. As a result cyanosis, bradycardia, apnea, and extensor spasm accompanied attempts at anesthesia. Wakening was slow, fatigue severe, and convulsions common. Chemical studies reflected these changes. Intubation of the trachea with a nasotracheal tube inserted while the animal was awake and ventilation with air during the induction prevented these abnormalities.

The table shows the mean results of the biochemical studies done on 6 macaque monkeys which were anesthetized with several patterns of current and application with a nasotracheal tube in place. An assumption was made that the breath-holding could be a function of the particular types of current applied. As a result, several different types were applied in an effort to achieve anesthesia without this undesirable effect (fig. 2). Satisfactory anesthesia could be established only if the trachea was intubated and pulmonary ventilation carried out. The breath-holding response to current apparently is a species peculiarity.

A Model 100-A generator,* producing a sinusoidal wave pattern with a range of frequency varying from 300 to 3000 cycles per second (cps) and functioning with a fixed amperage output (± 2 per cent), was found to be the best instrument for use on monkeys. Induction was less "rough" than that produced by other generators, but it did lead to Valsalva and cardiac slowing. Intubation of the trachea definitely improved its efficiency. At 1500 cps, fine subcutaneous electrodes produced burns when this instrument was employed. Similar burns were produced in the guinea pig and dog, as well as in monkeys.

DISCUSSION

The following observations are based on the findings in this study of electrical anesthesia on the macaque monkey.

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About the Authors

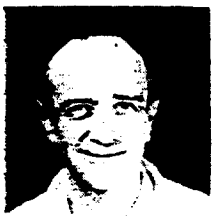

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Fig. 1. Monkey is supine on slightly troughed table, 5 to 7 degrees head-up, with head immobilized by ⅜ inch plywood "collar" fastened to table base by wing nuts and ¼ inch bolts. Elbows cannot be bent because of padded cylinder tied to table. Cylinders are hinged lengthwise to expedite placing around upper limb. Lower extremities are immobilized by strapping thighs to table and tying feet to distal end of table.

1. There is no necessity, in producing electrical anesthesia in the macaque monkey, for direct current plus a square wave of DC or AC origin. The stimulating "spike" may be a square wave of any origin or a sinusoidal wave, and may be used with or without direct current. Van Harreveld and associates's original concept, that the effect of electrical anesthesia is consequent to rapid, repetitive stimuli of sufficient strength, appears to be correct, at least in the macaque.

2. When direct current is not employed, subcutaneous needles or stainless steel safety pins can be used for electrodes.

3. Constant voltage does not produce as smooth an induction as does constant amperage.

4. A motor-driven potentiometer for controlled speed and smoothness of input is a necessity.

5. High frequencies, over 1000 cps, offer no advantage over those of 500 to 1000 cps, except toward a smoother induction. However, burns are noted when fine subcutaneous needles are employed.

6. Narrow waves appear to cause less discomfort than the broader ones, but require more voltage to produce a given peak amperage.

7. A nasotracheal tube prevents most of the physiological and biochemical disturbances.

Another observation arose from this study. A test animal was subjected to electrical anesthesia using the rectal-brow electrode placement pattern. When anesthesia had been achieved, a shielded pickup electrode working through a recorder was applied to a series of transverse sites on the long axis of the body. The electrode applied to the

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Table

MONKEYS: INTUBATION WITH NASOTRACHEAL TUBE NO. 20

	Resting	EN effected	EN + 1 hour	End EN + ½ hour	End EN + 24 hours
pO_2	110	87	96	94	
pCO_2	36.5	47	33.6	35	
pH	7.485	7.135	7.487	7.5	
Glucose	125	180	145	105	
Blood pressure	178/100	205/120	175/100	165/90	
Pulse	218	248	228	234	
Creatinine	1.1				3.0
SGOT	75				73.0

MONKEYS: INTUBATION WITH NASOTRACHEAL TUBE NO. 20 AND VENTILATED WITH AIR

pO_2	109	98	118	98	
pCO_2	34.8	37	35	34.8	
pH	7.46	7.22	7.392	7.46	
Glucose	94	160	103	88	
Blood pressure	170/105	190/130	170/100	170/100	
Pulse	250	275	220	236	
Creatinine	0.9				1.5
SGOT	68.0				75.0

EN = Anesthesia produced by current application. Note fall in pH consequent to induction. without significant change in pCO_2; this has been interpreted as metabolic acidosis consequent to muscle activity. Rapid disappearance of acidosis when anesthesia is achieved supports this concept.

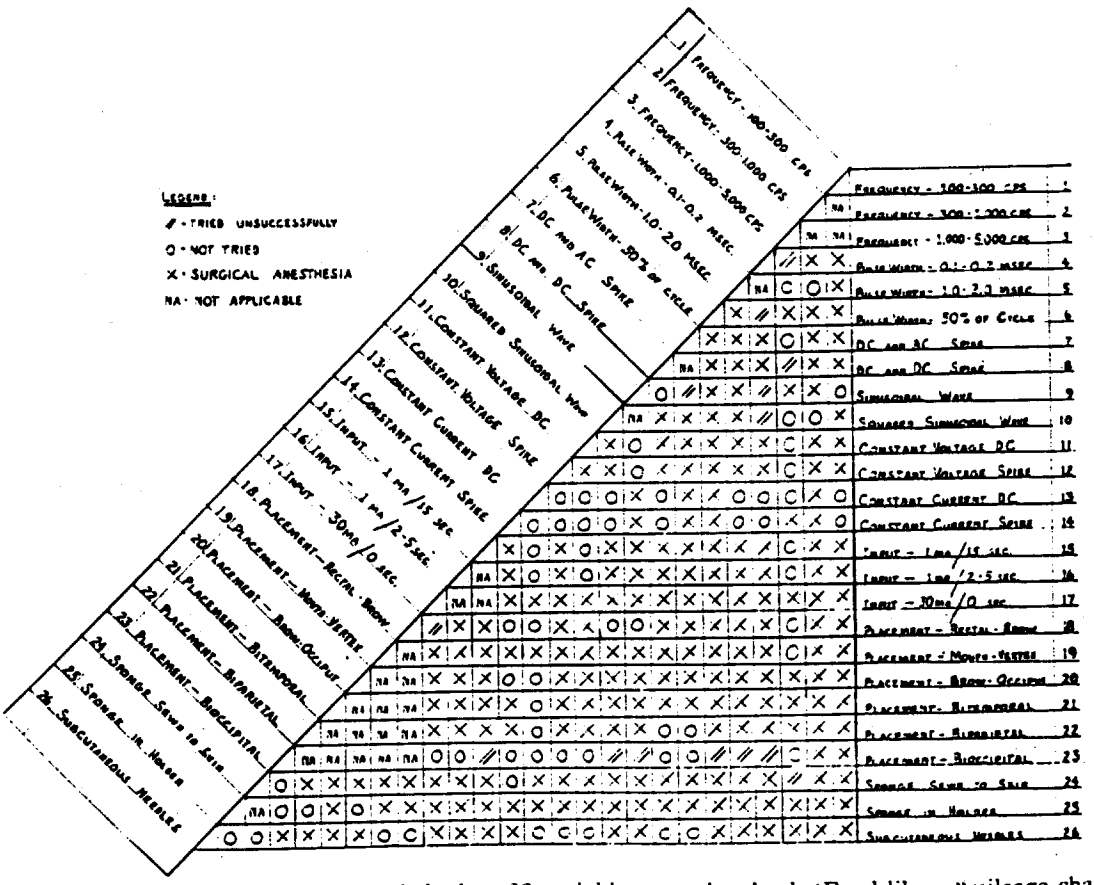

FIG. 2. Tabulation of combinations tried when 26 variables were involved. (Read like a "mileage chart.")

skin picked up a certain small amount of current. When the needle was inserted into the subcutaneous area, a greater voltage was recorded.

The needle electrode was inserted into subcutaneous tissue, muscle, vein, aorta, vertebra, intervertebral space, subdural space, and viscera (kidney, liver, brain), and the pickup was exactly the same at a given transverse level. The voltage picked up varied according to the site on the long axis of the body; but at any one site, it was constant. Thus, we have evidence that the body acts as a mass conductor, and there is no obstacle posed to the passage of current by bone and other tissues.

SUMMARY

Intubation of the trachea and ventilation with air during induction allow electrical anesthesia to be achieved easily in the macaque. Physiological and biochemical studies under these circumstances showed no deleterious effects in the macaque subjected to anesthesia produced by electrical current. The current can be applied in almost any "spike" form, provided the stimulus is rapid, rhythmic, repetitive, and of sufficient intensity.

Generic and Trade Names of Drugs

Lidocaine—Xylocaine

REFERENCES

1. Smith. R. H.. Goodwin. C.. Fowler. E.. Smith. G. W. and Volpitto. P. P.: Electronarcosis Produced by a Combination of Direct and Alternating Current. A Preliminary Study. I. Apparatus and Electrodes. Anesthesiology 22:163. 1961.

2. Smith. R. H.. Gramling. Z. W.. Smith. G. W. and Volpitto. P. P.: Electronarcosis by Combination of Direct and Alternating Current. 2. Effects on Dog Brain as Shown by EEG and Microscopic Study. Anesthesiology 22:970. 1961.

3. Smith. R. H. and Cullen. S. C.: Electronarcosis by Combination of Direct and Alternating Current. 3. Electrodes and Electrode Holders. Anesthesiology 23:682. 1962.

4. Smith. R. H.. Rovno. D.. Bechard. R. and Cullen. S. C.: Electronarcosis by a Combination of Direct and Alternating Current. 4. Effects on Some Physiologic Processes in the Dog. Anesth. & Analg. 43:59 (January-February) 1964.

5. Smith. R. H. and Cullen. S. C.: Electronarcosis —A Progress Report. Amer. J. Med. Electronics 5:308. 1962.

6. Smith. R. H.: Electrical Anesthesia. Edited by John Adriani. Springfield. Illinois. Charles C Thomas. Publisher. 1963.

7. Smith. R. H. and Cullen. S. C.: Electrical Anesthesia Produced by a Combination of Direct and Alternating Currents. J. Amer. Vet. Med. Assoc. 143:712. 1963.

8. Van Harreveld. A.. Plesset. M. S. and Wiersma. C. A. G.: Relations Between Physical Properties of Electric Current and Their Electronarcotic Action. Amer. J. Physiol. 137:39, 1942.

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