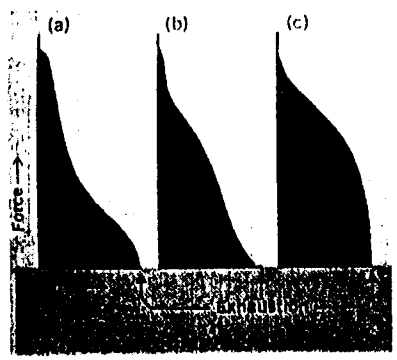


Fig. 1. Patterns of energy expenditure, based on ergograms.

Fig. 2. Decrease of muscle force with weight lifting.

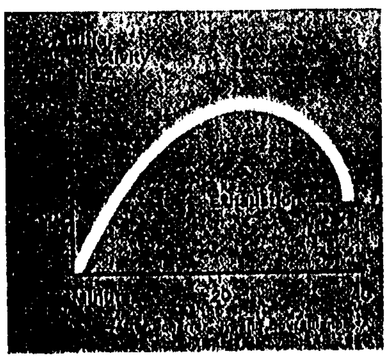


Fig. 3. Increase of electric activity of muscle in weight lifting.

are valuable for short-term benefit in emergencies. If misused, they are merely goads that hasten exhaustion. Considerable success has been reported with the monoamine oxidase inhibitors, and with psychic energizers having other types of action. Vitamins are of no help unless the patient is suffering from a specific deficiency. The same may be said for hormones. Adrenocortical dysfunction, however, is a common feature of chronic fatigue. If the disorder is one of hypofunction, stimulation with ACTH may help, but this may be harmful if mineralocorticoids are excessive. Androgens and other anabolic steroids are popular in some quarters for increasing energy, but their disadvantages probably outweigh their effectiveness.

The value of minerals for treatment is difficult to assess. Administration of iron relieves fatigue when iron stores are depleted, but not otherwise. In hot weather, salt tablets may prevent heat exhaustion but not fatigue of other types, and they delay acclimation. H. Laborit (Paris) found that sodium delayed both exhaustion and recovery in swimming rats. Calcium, magnesium and potassium delayed exhaustion but sped recovery.

Because aspartic acid and its amide asparagine are storage depots for ammonia and have a place in the urea cycle, Laborit tested magnesium and potassium aspartates in rats. Ammonia was efficiently removed from the circulation, and performance (swimming) was greatly improved. Given to athletes, these salts had a more striking effect in speeding recovery than in delaying fatigue. Magnesium and potassium aspartates have been used for treatment of chronic fatigue. Although some investigators reported good results, others found them no more effective than a placebo.

If ammoniemia is the problem, it can be combated in other ways. Administration of certain antibiotics curtails fermentation of protein in the intestine, thereby limiting the release of ammonia. The same goal can be attained more safely by a low protein diet. But this would rarely be effective in banishing fatigue.

Drugs, hormones and dietary measures may help in managing chronic fatigue, but reeducation is more important. The patient must learn to work efficiently and use his leisure to good purpose. Well directed activity, physical or mental, is often the best means of taking the tired mind off its troubles.

electronarcosis by a combination of direct and alternating current:

4. EFFECTS ON SOME PHYSIOLOGIC PROCESSES IN THE DOG

ROBERT H. SMITH, M.D.
DAVID ROVNO
ROBERT BECHARD
STUART C. CULLEN, M.D.
San Francisco, California*

THIS STUDY is part of a continuing inquiry into the effects of this form of electronarcosis on dogs. Earlier studies[1] indicated that there were no deleterious effects produced in the brains of test animals. In the present investigation, observations were made on the effects of this form of electronarcosis on: (1) ventilation, (2) blood sugar and blood pressure, (3) body temperature, (4) pregnancy, (5) ability to perform learned tricks.

In addition, attempts were made to ascertain whether there was any correlation between the current required to produce electronarcosis in a dog and the dog's total weight and skull thickness.

METHODS

Electronarcosis was produced by a combination of direct and alternating currents in the manner described previously.[1,3] Twelve mongrel dogs of both sexes, varying in weight from 10 to 28 kg. were used in these studies.

Study No. 1 — Each of 5 dogs, placed awake in the prone position, had topical anesthesia applied to the pharynx, and a No. 40 endotracheal tube inserted. The cuff was inflated when the tube was in the proper position and after the trachea had been anesthetized by dyclonine injected via a spray-tube[1] incorporated in the endotracheal catheter. After the dog had rested for 30 minutes, the catheter was connected to a Collins 9-liter spirometer with a carbon dioxide (CO_2) absorber. Respiratory rate, tidal, and minute volumes were recorded for 15 minutes and average values obtained from the graph.

Electronarcosis was then induced and recording resumed. As soon as electronarcosis was established, tidal volumes were averaged from a 6-minute spirometer recording. Thirty minutes after electronarcosis had been established, a third set of values was obtained in the same manner. There was sufficient consistency in the rate and tidal volume to make an average reliable.

The spirometry studies frequently were spoiled by the onset of panting. This heat-loss mechanism moves large

*Department of Anesthesia, University of California Medical Center, San Francisco, California.

This work was supported in part by the Anesthesia Research Foundation, University of California Medical School Grant No. 02 Breon Fund, and United States Public Health Service Grant 2G-63 (C4).

quantities of gases per unit time and modifies normal ventilatory values markedly. Muscle activity was the commonest cause for the temperature rise which evoked the panting, and such activity is difficult to avoid in a dog which has undergone endotracheal intubation while awake.

The spirogram was used in the study if the panting was present only in the resting state, and was not too violent. Marked elevation of temperature evokes panting at rates of 200 and over per minute, but excitement and anxiety appear to be the biggest factors in respiratory rates of 60 to 100. These states disappeared with the induction of electronarcosis.

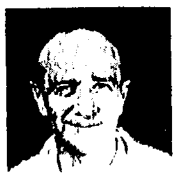
Study No. 2 — Under infiltration with 5 ml. of 1 per cent lidocaine without epinephrine, a nylon catheter was placed in the right femoral artery of each of 7 dogs. The dogs were placed in the prone position and blood pressure recorded by means of a Statham® strain-gauge and a Grass recorder. Blood pressure was recorded until stable for at least 15 minutes. At that time two 5-ml. arterial blood samples were drawn anaerobically, and analyzed in duplicate for pO_2, pCO_2, and pH in a Beckman® physiological gas analyzer. Correction for O_2 saturation per cent at 38° C. was made by using the Severinghaus[5] formula, modified for dogs by using 38° C. instead of 37° C., as for human beings.

Samples were drawn again as soon as full electronarcosis was achieved, after ½ hour, after 1 hour, and 15 minutes after ending electronarcosis. Blood pressure was recorded throughout the period of study. Blood samples were analyzed for glucose content and blood gas. The dogs breathed room air spontaneously, and were not intubated. Body temperature was observed and recorded at the time of arterial sampling.

Study No. 3 — After stabilization of rectal temperature, 6 dogs were subjected to electronarcosis for 1 hour and rectal temperatures recorded. Forty-eight hours later the dogs were given 0.6 mg. of scopolamine hydrobromide, rectal temperatures were taken until stable, and electronarcosis was repeated in only 1 dog for 1 hour, during which rectal temperatures were taken. The same procedure was repeated 48 hours later except that 0.6 mg. of atropine sulfate was used instead of scopolamine. Throughout these studies the pulse was recorded, to establish time limits for the the study, as tachycardia was considered an indication of a persistent anticholinergic drug effect.

The rectal temperature of 3 dogs known to have high current require-

About the Authors



Dr. Smith

★ ROBERT HUDSON SMITH, M.D. is Assistant Professor at the University of California Medical Center in San Francisco, and Chief (Acting) of Anesthesia at the San Francisco General Hospital. He received the B.S. and M.D. degrees from the University of Washington, Seattle, Washington, in 1950.

★ DAVID ROVNO is a fourth year medical student at the University of Pennsylvania, Philadelphia, Pennsylvania.

★ ROBERT BECHARD is a fourth year medical student at the University of California Medical School in San Francisco.

★ STUART C. CULLEN, M.D. is Professor and Chairman of the Department of Anesthesia at the University of California Medical Center in San Francisco. He received his M.D. degree from the University of Wisconsin, Madison, Wisconsin, in 1933.

ments for the induction and maintenance of electronarcosis was observed for the effects on body temperature of prolonged induction with considerable muscle activity, and of rapid inductions with less muscle activity. Slow induction increase was 1 milliampere per 15 seconds. Fast induction increase was about 1 milliampere per 5 seconds.

Five dogs were permitted to develop moderate elevations in body temperature through violent muscular activity while their heat-loss mechanisms were bypassed by endotracheal intubation. Then they were extubated, and permitted to pant until their temperatures were normal (38° C. rectal). The effects of endotracheal intubation on body temperature were studied in the 6 dogs undergoing spirometry.

Study No. 4 —Three pregnant female dogs were subjected to 1 hour of electronarcosis at least 6 times in the course of their pregnancy.

Study No. 5 — Six dogs were trained to do a standard series of tricks. Each was taught to "heel" while the trainer walked, to sit on its haunches with the forelegs held up, to jump through a hoop, and to mount a small platform and turn around. Every time, thereafter, that one of these animals underwent electronarcosis, the ability to perform these tricks was tested as soon as possible after the end of the electronarcosis.

Study No. 6 — Skull radiographs were taken of each of 8 dogs in which electronarcosis had been established several times. The animal's current requirements were known. The radiographs, with a metal centimeter marker for measurement, were lateral exposures, taken at 40 inches. The skull thickness at the site of the vertex electrode placement was measured by a specialist in veterinary radiology.

RESULTS AND DISCUSSION

In no test animal was there noted a decrease in tidal volume. The minute volume decreases were consequent to slowing of rate. The resting respiratory rate of these dogs is normally in the range of those rates recorded under electronarcosis. The average resting tidal volume was 200 ml.; the rate 54. After electronarcosis was established, the average tidal volume was 390 ml.; the rate 20. One hour later (under electronarcosis) the average tidal volume was 300 ml.; the rate 28.

Table 1 — The data on blood gas may be summarized by the statement that in no animal did the arterial O_2 saturation fall below 91 per cent or the arterial pCO_2 rise significantly. The low pCO_2 values obtained in some animals were the result of panting. One animal showed a fall in pH from 7.42 to 7.33 despite a steady rise in pO_2. This fall accompanied a small rise in pCO_2, 38 mm. to 43 mm., and is construed as reflecting a metabolic acidosis, not marked hypoventilation.

In all the test animals but one, there was noted a decrease in pO_2 below the resting, pre-electronarcosis level at some point in the study. The greatest fall was 14.6 mm. of mercury, a fall in saturation of less than 2 per cent. One dog which had a control pO_2 of 62 showed a steady improvement in pO_2 as the test progressed.

On the average, there were mild to moderate rises (5 to 20 per cent) in systolic pressures when electronarcosis was induced and maintained, with reversion to resting levels after electronarcosis was terminated. Diastolic pressures increased 11 to 50 per cent in 3 dogs, and in 1 dog there was a fall in diastolic pressure of 25 per cent with no change in systolic pressure.

Blood pressures were markedly elevated during electronarcosis in 2 animals. However, both started with high blood pressures, and the changes were small when considered as a percentage of the starting figure. One of the highest percentage blood pressure rises, 20 per cent, was found in a male dog which has had surgery 8 times under electronarcosis and has undergone electronarcosis over 30 times.

Temperature changes were chiefly upward when electronarcosis was induced, and the rise varied from 0.2° to 1.8° C. Fifteen minutes after the end of electronarcosis, the temperatures were still elevated, but less so than during electronarcosis. One dog had a lower temperature than at the start of the procedure.

Blood glucose levels varied markedly. One dog showed a decrease in blood glucose of 35 mg. per 100 ml. All the others demonstrated increases varying from 5 mg. to 225 mg. per 100 ml. These figures

Table 1

RESULTS OF STUDIES MADE VIA INTRA-ARTERIAL CATHETER

Dog	Resting pH	Resting pCO_2	Resting pO_2	Resting Hemoglobin per cent saturation	Full electronarcosis pH	Full electronarcosis pCO_2	Full electronarcosis pO_2	Full electronarcosis Hemoglobin per cent saturation	One-half hour full electronarcosis pH	One-half hour pCO_2	One-half hour pO_2	One-half hour Hemoglobin per cent saturation	One hour full electronarcosis pH	One hour pCO_2	One hour pO_2	One hour Hemoglobin per cent saturation	Fifteen minutes post-electronarcosis pH	Fifteen minutes pCO_2	Fifteen minutes pO_2	Fifteen minutes Hemoglobin per cent saturation
1	7.43	34	96.1	97	7.43	33	91.8	96	7.43	31	90.8	96	7.40	33	86.4	96	7.41	34	83.5	96
2*	7.39	31	92.0	96	7.36	26	92.0	96	7.39	26	93.6	96	7.39	27	73.0	95	7.43	19	98.9	98
3	7.42	30	97.0	97	7.40	30	93.4	96	7.37	36	87.1	96	7.41	31	92.4	96	7.46	26	97.0	98
4*	7.38	32	94.6	96	7.32	27	98.4	98	7.34	25	91.4	96	7.35	25	90.3	96	7.36	28	93.5	96
5	7.39	36	95.0	96	7.39	33	94.0	96	7.37	30	88.0	96	7.39	31	88.0	96	7.39	34	88.0	96
6	7.36	42	90.0	96	7.24	38	77.8	94	7.35	39	75.6	95	7.43	23*	81.0	95	7.43	26*	94.0	98
7	7.42	38	62.0	91	7.34	42	73.5	94	7.34	43	77.7	95	7.33	43	69.3	93	7.41	33	80.0	95

Dog	Resting Temperature	Resting Blood pressure	Resting Sugar	Full electronarcosis Temperature	Full electronarcosis Blood pressure	Full electronarcosis Sugar	One-half hour Temperature	One-half hour Blood pressure	One-half hour Sugar	One hour Temperature	One hour Blood pressure	One hour Sugar	Fifteen minutes Temperature	Fifteen minutes Blood pressure	Fifteen minutes Sugar
1	38.4	113/80	105	39.0	138/90	110	38.6	150/90	100	38.6	130/90	103	38.6	120/80	100
2*	39.6	190/140	161	39.9	200/160	323	41.2	190/150	386	41.0	190/150	210	40.0	195/140	330
3	38.8	140/80		39.0	158/95		39.0	140/84		39.0	150/58		38.2	135/80	
4*	39.2	190/90	150	41.0	200/100	206	40.2	160/100	190	40.0	Damped	200	39.7	150/100	240
5	39.0		170	39.8		145	39.9		150	40.1		135	39.5		180
6	38.5			39.0			39.0			39.0			38.8		
7	38.3	150/80	140	38.0	180/120	150	38.4	150/90	262	38.7	180/110	152	38.7	135/75	130

*Panted throughout entire procedure.

Table 2
SCOPOLAMINE EFFECT ON DOG TEMPERATURE
(6 dogs)

Resting	38.3° ± 0.2° C.
30 minutes after 0.65 mg. of scopolamine	37.9° ± 0.56° C.
120 minutes after 0.65 mg. of scopolamine	38.0° ± 0.0° C.
One dog's temperature rise with electronarcosis	38.8° to 39.0° ambient temperature 23.8° C.
Same dog after 0.65 mg. of scopolamine	39.1° to 39.6°

Table 3
ATROPINE EFFECT ON DOG TEMPERATURE
(6 dogs)

Resting	38.4° ± 0.72° C.
30 minutes after 0.6 mg. of atropine	38.1° ± 0.3° C.
120 minutes after 0.6 mg. of atropine	38.0° ± 0.37° C.
One dog's temperature rise with electronarcosis Ambient temperature 22.0° C.	38.7° to 39.2° — 0.5° C.
Same dog after 0.6 mg. of atropine	38.8° to 39.0° — 0.2° C.

Table 4
EFFECT OF INDUCTION DURATION ON TEMPERATURE RISE

Dog	Requirements	Temperature slow induction	Temperature fast induction
1	40 DC 37 AC	39.4° to 41.8° (EN #1)	39.1° to 40.0°
2	33 DC 42 AC	38.6° to 39.7° (EN #3)	38.2° to 38.6°
3	35 DC 35 AC	39.6° to 41.0° (EN #2)	38.7° to 39.6° (EN #6)

Note: EN #1, for example, is an abbreviation for the first time the animal was subjected to electronarcosis.

represent changes of 5 and 150 per cent over the resting levels.

One animal demonstrated a marked rise in blood glucose. He was quiet throughout the entire procedure, and no explanation for the change can be found except the possibility that there was electrode movement at critical times in the study. Electrode movement may result in alternately "lightened" and "deepened" anesthesia.

The elevation in blood sugar in 2 dogs paralleled an elevation in blood pressure. Both dogs were excitable in nature, and difficult subjects with which to work. The only reasonable explanation for these unexpected sugar and blood pressure rises is the plane of anesthesia produced by electronarcosis. As previously stated, the level appears to be the "analgesia and amnesia" 1-3 of Artusio.[6] Whether there is amnesia in dogs is a debatable point. Analgesia is present to a marked degree but psychic stimuli may persist, under electronarcosis, to produce these blood pressure and glucose elevations. In support of this possibility is the fact that it is possible, at times, to call quietly to a dog undergoing surgery and get a tail-wagging response.

Tables 2 and 3 — The results of the studies on the effects of scopolamine and atropine on body temperature are summarized in tables 2 and 3.

The observations on scopolamine and atropine were made because drying agents are necessary to decrease salivation in dogs turned supine for abdominal surgery. Unless secretions are decreased, pharyngeal suction must be used frequently or the dog will become seriously obstructed by its secretions.

Table 4 — In one dog with known high current requirements, a rise of 2.4° C. developed during a long induction, whereas there was an elevation of only 0.9° C. in a short one. In the other 2 animals, the difference between the long and short inductions was seen, but was less pronounced: 1.3° compared to 0.4° and 1.4° compared to 0.9° C.

Muscle activity during the preinduction and induction phases of electronarcosis is the most probable source of heat. Shortening the induction period is necessary, particularly in dogs with high requirements of current. When such a dog is encountered, and it becomes obvious that a standard induction will result in high temperatures, it has been found advisable to stop the procedure, permit the animal to pant until its temperature is normal, then proceed again with the induction at a much faster rate.

Table 5 — This table indicates that a dog, by panting, will lower its temperature 2.5° to 3.0° C. in an hour, if it is permitted to do so and if there is no struggling or excitement to increase heat output. Panting, in itself, is severe muscle activity, and as such, is productive of body heat, so the fall in temperature reflects a net decrease in body heat.

With intubation the temperatures of all 6 dogs undergoing spirometry became elevated from 0.2° to 1.2° C. Starting temperature was 38.4 ± 0.90° C. Temperature after 30 minutes of electronarcosis was 39.0° ± 1.76° C.

The effect of the endotracheal tube on the prevention of heat loss has been noted previously. Panting is a means of heat production rather than of heat loss in the dog with a tube in its trachea; the usual air-stream over the big A-V shunts in the dog's tongue is diverted by the tube, while the exertion of panting raises body heat output.

Effects on Pregnancy — The pregnant females did not abort, and delivered normal pups at term. Pregnancy was one of the contraindications to electronarcosis listed by Robinovitch in Gwathmey's "Anaesthesia."[7] We have seen no reports by other investigators on the effects of other forms of electronarcosis on pregnancy. One of our pregnant females underwent a total of 6 hours of electronarcosis in the first week of pregnancy, and delivered 10 normal live pups at term. The other 2 females averaged 1 hour per week of electronarcosis during their pregnancies, and delivered at term.

Effects on Memory — The impact of electronarcosis on learned tricks could not be quantitated; the test animals performed their tricks as usual whether the period of electronarcosis had included operations or not, and irrespective of the duration of the electronarcosis. One precaution must be observed: Tight ties on the legs for long periods of time leave the animals unable to walk until circulation returns to normal, and under these circumstances, testing is useless. The study revealed no evidence of any loss of the sense of balance in a dog after 2 hours of electronarcosis.

Table 6 — There appeared to be no correlation between body weight or skull thickness and the current requirements for the production of electronarcosis.

The heaviest dog, a 28-kg. female, had

Table 5

EFFECT OF PANTING ON BODY TEMPERATURE

Dog	Start temperature	10 minutes	20 minutes	30 minutes	1 hour	Total fall
1	42.5°			40.5°	39.8°	2.7°
2	41.7°	41.4°		39.7°	38.7°	3.0° (70 minutes)
3	41.0°	41.0°	39.6°	39.0°	39.4°	1.6°
4	41.2°		40.4°	39.8°	38.1°	3.1° (drank 500 ml. water)
5	40.8°	40.7°	40.5°	39.7°	38.5°	2.3°

Table 6

TABULATION OF CURRENT REQUIREMENTS AND SKULL THICKNESS AND BODY WEIGHT

Dog	Weight kg.	Required DC	-	AC	Skull thickness mm.
1	26.3	33	—	42	4.0
2	28.0	16½	—	10	3.6
3	23.5	20	—	9	3.2
4	19.1	20	—	17	4.0
5	21.4	20	—	14½	2.4
6	26.3	22	—	20	5.2
7	22.5	20	—	15	3.2
8	21.1	20	—	7	4.0

the lowest current requirements; the next heaviest, 26.3 kg., had the highest. The skull thickness was no criterion of current requirements. In general, it has been found that the more nervous and excited the dog, the higher the requirements. This description applies to the general temperament, not to a temporary state.

CONCLUSIONS

In dogs in which electronarcosis was produced by the technic reported:[1,3]

1. Minute ventilatory volume fell slightly under electronarcosis, not because of decrease in tidal volume but because of slowed rate.

2. Arterial oxygen saturation percentage did not fall below 91 per cent. Arterial pCO_2 was not elevated above normal levels in any test animal.

3. By panting, a dog can lower its body temperature 2½° to 3° in an hour. Intubation of the trachea raises the body temperature by blocking panting. Rapid inductions of electronarcosis produce lower body temperature elevations than slow ones. Muscle activity rather than central nervous system stimulation probably is the chief factor in temperature rise.

4. Scopolamine, 0.65 mg., and atropine, 0.6 mg., are adequate drying dosages for large dogs and do not contribute to elevation of the body temperature. With electronarcosis, in only one dog, to which 0.65 mg. of scopolamine had been administered, did a moderate temperature elevation occur.

5. Electronarcosis did not cause abortion in 3 pregnant females.

6. Electronarcosis did not impair performance of learned tricks.

7. There appears to be no correlation between the current requirements of a given dog and either its weight or skull thickness.

SUMMARY

Continuing previous inquiries into the effects of electronarcosis by a combination of D.C. and A.C. on some physiologic processes in the dog, this paper reports further investigations on additional areas, including ventilation, blood sugar and pressure, body temperature, pregnancy, and memory.

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. I. Apparatus and Electrodes. Anesthesiology 22:163 (March-April) 1961.

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

3. Smith, R. H. and Cullen, S. C.: Electronarcosis by a Combination of Direct and Alternating Current. III. Electrodes and Electrode Holders. Anesthesiology 23:682 (September-October) 1962.

4. Smith, R. H. and Bonner, M. S.: Endolaryngeal Topical Anesthesia. Anesthesiology 20:121 (January-February) 1959.

5. Severinghaus, J. W.: Oxyhemoglobin Dissociation Curve Correction for Temperature and pH Variation in Human Blood. J. Appl. Physiol. 12:485 (May) 1958.

6. Artusio, J. F.: Ether Analgesia During Major Surgery. JAMA 157:33, 1955.

7. Gwathmey, J. T.: Anaesthesia. New York, D. Appleton & Co., 1914.