

ELECTRIC ANAESTHESIA AND ELECTRO-NARCOSIS.

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INTRODUCTORY.

IN the following pages the use of electricity as an anaesthetic agent for man and animals is discussed. An attempt is made to assess the existing state of knowledge, but the issue is a complex one, and there are many gaps and contradictions in the story. Attention is later given to the now familiar use of electricity for the supposedly humane destruction of animals, in particular the pig, dog and cat, and these practices examined in the light of the reliable evidence.

HISTORICAL ASPECT.

The concept of electrical anaesthesia is not in any sense new. According to Sir Leonard Hill (1935), Benjamin Franklin (1706-1790) made experiments in this direction, and was followed in the next century by Benjamin Ward Richardson (1869).

D'Arsonval (1890) noticed that currents of a frequency considered high at that date could induce a certain degree of narcosis. Hutchinson (1892) and Pampilion (1901) recorded that anaesthesia could be induced by appropriately applied I.D.C.,* obtained by the first worker by means of a ribbon vibrator, and by the second with a segmented wheel. Attention was then focussed on the issue by the classical studies of Leduc (1902) and his school. Over the next decade Robinovitch contributed considerably to the literature and subject, which seems then to have passed into almost total neglect until recent years.

TYPES OF ELECTRIC ANAESTHESIA.

The possibilities appear to be three-fold :

- (1) Local anaesthesia, by electrical interference with the passage of afferent impulses, as on the limbs.
- (2) Spinal anaesthesia : similar interference with nerve-function in the cord.
- (3) General anaesthesia : electrical interference with the receptor mechanisms in the brain. This may be either of brief duration, as produced by a single pulse of high density ; or prolonged, as produced by the sustained application of weaker currents.

* D.C. stands for direct current, I.D.C. for interrupted direct current.

In the greater part of the experimental work it would appear that (2) and (3) have been concerned together.

(1) *Local anaesthesia produced by electrical means.*

This aspect has received the least attention. Robinovitch, however, discusses it in Gwathmey's *Anaesthesia* (1914). She states: "In clinical work we have applied electrical anaesthesia for local anaesthesia in numerous cases." Her technique was to apply D.C. interrupted 100 times per second and with a duration of pulse of 1 msec.* The anode and cathode were secured over the nerve trunks, the anode being proximal. The method was first employed in 1910 at the St. Francis Hospital, Hartford, Conn., for the amputation of the great toe of one foot and the great, second and third toes of the other. 54 V. provided a current of 4 mA. She then refers to other surgical interferences, including two further amputations of the toes (where 9 mA. was used), and a resection of the leg, using here 18 mA. Anaesthesia would appear to have been complete in all instances, but tingling sensations were complained of at the higher amperages and she recommends 4 mA. as the current strength, not to exceed 6 mA. Special emphasis is laid on the bloodless condition of the fields of operation as a result of vaso-constriction, and on the surgical advantage of this.

Hertz (1933) failed completely to obtain by similar means any measure of local anaesthesia whatever, but successful regional anaesthesia is reported by Kalendaroff (see p. 55).

(2) *Spinal anaesthesia produced by electrical means.*

This has involved the application of D.C. or I.D.C. between the posterior aspect of the trunk and the neck or other anterior part. Many workers have applied the cathode to the head itself, thus including the brain in the circuit. This circumstance complicates the issue by including the cerebrum, and combined spinal and general effects are then probably concerned. At present only true spinal effects will be considered.

Ivy and Barry (1931) applied I.D.C. (100 pulses/sec., of duration 1 msec.) between the lumbar region and the back of the neck in dogs. The current employed was low (the voltage was 4 to 12 V.). They report that complete immobility resulted, without loss of consciousness. Respirations were normal or somewhat augmented, the pulse-rate was slowed. When the circuit was broken, the animals recovered immediately, and repetitions for a period of 10 minutes on 6 successive days were without deleterious effect. They conclude, however, that too much muscular rigidity was developed for practical (surgical) purposes, and ascribe this tonus to the inductive effects of their segmented wheel interruptor. In conclusion they observe: "We believe that the induction of spinal anaesthesia with appropriately interrupted direct current has considerable promise and warrants further investigation. Such an investigation awaits the perfection of an apparatus that is free of faradization effects or one that yields an oscillographic curve with a square plateau

* 1 msec. = 0.001 seconds.

and adequate voltage. It is believed that such an apparatus would not produce the rigidity seen in the majority of dogs on the application of the current to the spinal cord, and would render surgical operation feasible."

Silver (1939) applied continuous steady D.C. between the anus and the shoulder in rats, and records immobilization effects on the hind-quarters only. The fore-quarters remained normal.

Recent work from Italy (Martini, Gualtierotti and Marzorati (1942)), reports the induction of complete spinal anaesthesia in the cat, and has included a study of the physiological mechanism. These workers employed what they term "Greek" current—sine-wave current half-rectified and clipped or squared by passage through a pentode valve operated at saturation. This is the equivalent for all practical purposes of the current employed in his classical studies by Leduc, and referred to below.

Applied to the exposed spinal cord the current resulted in total spinal dysfunction, as monitored by the electro-myelogram. They believe this action to be reflex, since freezing the cord at a level caudal to the site of stimulation suppressed the effect. They claim, moreover, to have demonstrated that the reflex involves the stimulation of specific inhibitory centres for the spine, situated in the diencephalon (hypothalamus), and they claim by a technique of neuro-section to have localized these accurately. What is of even greater physiological interest is their statement that the centres are multiple, each acting bilaterally but having specific control over its segment of the cord.

(3) *Spinal plus general anaesthesia produced by electrical means.*

This heading covers the greater part of the experimental studies on electric anaesthesia. Most workers have followed the technique of Leduc, applying I.D.C. between the loins and the head.

Leduc's experiments.—Leduc (1902) and his colleagues applied initially faradic current, but tonus was the invariable consequence. He therefore assayed I.D.C., obtained by the interruption of battery current by a segmented wheel, at interruption rates up to 200 per sec. and over a wide range of voltages. He is quoted in translation by Regensburger as follows: "The animal is placed in the circuit, placing on the shaved head a cathode formed of absorbent cotton impregnated with a solution of sodium chloride, and covered with a metallic plate; a wide anode is placed on the shaved back of the animal at the posterior extremity of the body: the interrupter being in operation, the e.m.f. is rapidly increased in the circuit until generalized contractures are produced, the animal falls on its side, the respiration stops; the indicator hand of the commutator is then brought backward until the respiration is re-established; at a certain degree of current, a tranquil and regular sleep is obtained, the respiration continues without modification, the heart functions normally, but all of the cerebral functions are suppressed; the animal, dog or rabbit, free, without fetters, remains lying motionless in a profound sleep, the muscles are relaxed; the animal, if one raises it by a fold of the skin, is flabby and completely inert; if it is pinched, pricked or cut, it does not react, unless by some reflex movements."

“ The duration of the sleep may be very prolonged ; we have some animals which have been kept asleep many times for over two consecutive hours without any alteration in their health. The establishment of the current does not seem to cause pain, for the animals do not utter a cry, aside from the contractions and contractures caused by the current, they do not make any movement of defence or of flight. If the current is established slowly, in order not to exceed the necessary dose and avoid contracture, there is a period of agitation, analogous to that which chloroform gives ; the sleep is then longer to obtain. . . . In summary, with these currents, one can instantly, without apparent pain, bring about the complete inhibition of the cerebral centres, leaving intact the centres of respiration and of circulation ; one thus obtains a tranquil, prolonged sleep, and a complete general anaesthesia. The somniferous action is regulated and is suspended as quickly as one can act on the electric current ; the sleep is not followed by any consecutive reaction.”

Later, Leduc arranged that the technique should be applied to himself, but his colleagues feared to push the experiment far, only 35 V. with a current of 4 mA. being reached. Leduc recorded his sensations as a complete loss of motor-power, and dimming of hearing and sensation generally. No pain as such was experienced, and he appears to have been incensed that the experiment was not carried further, believing that he would then have experienced complete anaesthesia. This belief is apparently supported by the work of Kalendaroff, but is challenged by Zimmern and by Hertz, as will be discussed later.

Robinovitch (op. cit.) reviewing the technique of this method, emphasizes that :

- (1) large storage batteries (100–200 ampere-hours) only should be used for current, as the latter must be steady.*
- (2) for the same reason the supply (to the patient) must be independent of that driving the motor of the interruptor.
- (3) self-inductance must be eliminated from the circuit, as by the use of graphite rheostats, etc.

Ross and Allen (1943) investigated electro-narcosis in dogs by a technique similar to Leduc's. Voltages up to 17 provided currents of 2–10 milliampères, interrupted mechanically from 80–470 times per second. Their results were essentially the same, and are summarized by them as follows :

“ 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

* This stipulation does not continue to apply to-day, when less cumbersome and costly stabilizing devices are available, such as the feed-back circuit described by Plesset (1942) and employed by the American workers (q.v.).

It is necessary over the whole field to recognize the distinctions between constant-voltage and constant-current conditions. The large storage batteries of Robinovitch, for example, provide only for constant *voltage*, and the current passing will depend on the very variable resistance of the animal, and on back-E.M.F. It is always the current-density that is the physiologically critical determinant.

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 hyperpnoea, 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. The subject carries such great implications that even the relatively meagre success to date still opens the way for much improvement. Further experimentation is still to be done at the higher frequencies* and under many conditions. It appears that there are still factors to be determined. . . . In conclusion, it may be stated that the optimal results, with the current 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.”

Silver (1939) reports work on rats, and Silver and Gerard (1941) on the frog, rat and dog. Here continuous D.C. was employed. The cathode was inserted in the mouth and the anode in the anus, and a current of 10 mA. was passed. This resulted in rats in “a completely unresponsive state which could be maintained for hours.” The animals were quiescent under severe noxious stimuli (cutting, burning, powerful electric shocks). When the circuit was broken (after halving the current for one minute and then reversing for 10 seconds‡) the rats recovered normal reflex thresholds within 5 minutes and complete normality within 10 minutes. Repetitions totalling 10 hours of treatment failed to lead to any detectable physiological defects or neuro-histological changes. In the second of the studies, where dogs were included, these findings are confirmed, and the authors conclude that a current-density of 1 mA./mm.² of cross-section of the cord is required for the effect. Blood-pressure, heart-rate, and respiration were not significantly affected. In one dog the current was passed for a period of 8 hours without ill-effect. Complete recovery on breaking circuit was invariable, but considerably slower in the dog, though normal reflexes were present in 15 minutes.

Of special veterinary interest is the report of Kosler (1928) who employed an electric method in cattle. Direct current at 100–120 V. was passed between a copper electrode on the loins and a brass bit in the mouth; the current strength is not known. The animals sank to the knees and then to the side in lateral recumbency, with apparently complete loss of consciousness. Recovery was complete in 2–3 minutes of switching off. The procedure was repeated on the same animals without harm. Frickinger (1928) confirms these results.

Further studies with this type of current are considered under a later heading, but before leaving the present topic reference should be made to a communication from Professor Kalendaroff of the Biophysics Section of the

* The influence of frequency has since been studied in America (see p. 67) and in Italy (p. 58). But the conclusions arrived at are discordant.

† The recommendation of slow induction by these workers is not in accordance with Leduc (p. 54) and certain other workers (Wiersma *et al.*; Kalendaroff). In the light of Leduc's observations this may account for their difficulties, and perhaps the motor effects.

‡ No reason is given for this procedure, and its influence on the course of events is not indicated. Its rationale is presumably referable to back-E.M.F.

Institute of Experimental Medicine, U.S.S.R., for a copy of which I am indebted to Major C. W. Hume. The letter refers to a publication by Hume (1935) in *Nature*, and states: "We are trying electro-narcosis experiments not only with animals (frogs, rabbits, dogs), but also with human beings, both sound and insane persons. For this purpose we use Leduc's currents. . . . All experiments are verified on ourselves."

"We are thus able to produce: (1) a condition analogous to general narcosis with total unconsciousness, with loss of sensitiveness and motility; (2) a condition analogous to sleep, with integrity of reflex movements and loss of sensitivity; (3) loss of sensitiveness localized in certain domains with integrity of tactile perception and complete consciousness."

"The stage of narcosis depends markedly on the adaptability of the organism to electric current. By increasing the current step by step, very smoothly and slowly, a considerable current (5 mA.) could be applied without marked symptoms of electro-narcosis. A rapid increase of the current up to 5 mA. causes a deep narcosis." The letter then mentions certain therapeutic applications of the current, including ". . . the treatment of mental diseases, the excitability of the brain in this case being markedly changed."*

Unfortunately, further details of these investigations do not appear to be available in this country. Their special interest lies in the unequivocal declaration of the induction of both general and local anaesthesia by means of the Leduc current, with human (subjective) confirmation.

(4) *General anaesthesia produced by the application of electric current across the head.*

This is the technique commonly employed in electric stunning in abattoirs. It is also the technique of electro-convulsant therapy in man. In both cases the current is passed for brief periods, but recently the current has been applied in psychiatric practice across the head continuously for long periods. (Wiersma *et al*; Paterson and Milligan). A fundamental difference between the present issue and those previously considered is the high voltages and seemingly enormous amperages that are employed.

Electric stunning of animals.—This subject has received critical attention from numerous investigators (Hill, MacSwiney and Clinton (1932); Symes, Hill and Hobday (1932); Dryerre and Mitchell (1934); Regensberger (q.v.); Anthony (1932); Clark and Tweed (1932); Müller (1932); and others). Single-phase rectified, alternating and three-phase currents are variously employed, applied in the case of the first two across the head, in front of or behind the ears; in the last case between the base of the ears and the forehead ("Iwel" Electro-lethaler). The voltage is usually some 70–80 V. and the resulting current of the order of 0.5 to 1.0 amp. r.m.s. (Hill and MacSwiney). The time of application of the current varies considerably in practice from a few seconds up to half a minute, and on its withdrawal the animal either relaxes immediately or goes into convulsions followed by relaxation. For

* It is noteworthy that this reference to the use of electric current in mental disease antedates by three years the pioneer work of Cerletti and Bini (1938) on electro-convulsant therapy.

periods varying from one to several minutes it then has every appearance of complete insensibility and fails to react to painful stimuli.

Ivy and Barry (1931) studied the effects in dogs. They employed I.D.C. obtained with a segmented wheel from storage batteries, with electrodes placed in the ears. (Reference to their observations on spinal anaesthesia has already been made). The interruption rate varied from 100–200 pulses per second, the pulse duration from 1 to 3 msec., and the time of application from 5 to 15 seconds. They conclude their long series of observations as follows: "The various types of current used will stun dogs. . . . The most efficient current is one of 72 V. interrupted 6,000 times a minute and passing 3/10 of the total time—each stimulation lasting 15 seconds. The average time elapsed before pain was felt* after this current was 4 minutes and 14 seconds. The shortest time was 2 minutes and the longest 12 minutes. The minimum effective time for application of the current is 10 seconds, the optimum being 15 seconds. . . . The stimulation serves to inhibit cerebral activity as judged by the loss of reaction to painful stimuli, and the absence of the drop reflex, climbing reflex. . . ."

The authorities cited earlier all assert that consciousness is lost, though almost all concede that this conclusion is presumptive.

Frostig, van Harreveld, Reznick, Tyler, Wiersma (1944) essayed a modification of this technique in dogs and man. 60-cycle A.C. was applied between electrodes placed behind the ears of dogs at such a voltage (unstated) as would supply a current of 300 mA., which was maintained for 30 seconds and then reduced to about 50 mA. (till respiration was restored. This they designate their "narcosis-level"). During the initial phase the usual tonic phenomena were produced, but with reduction of the current a condition of narcosis resulted in the majority of dogs "which could be maintained for hours." Recovery was complete within a few minutes of breaking circuit. In a minority of their dogs, what is termed a "hyperkinetic reaction" resulted instead of the narcosis, the characteristics of which recall the delirious phase of inhalation anaesthesia, in a modified form. This was partly dependent on the manner of induction, but is ascribed by them largely to idiosyncrasy, an aspect which is discussed later.

These workers used in these studies sine-wave A.C. from the mains instead of the traditional I.D.C., since earlier studies of van Harreveld and Kok (1934) and Wiersma *et al.* (1942) had indicated respectively that sine-wave current could be used, and that there was no significant difference in effect between this and square waves. These appear to be the first records of the use of A.C. for electro-narcosis (as opposed to stunning).

The objective of this team of workers was a modification of electro-convulsant therapy in psychiatry, and their results in the dog led them to apply the technique in human subjects. They report on over 100 treatments of 9 patients. The human reactions combined the narcotic and the hyperkinetic types of reaction in varying degree, but the techniques of induction were not entirely the same as for the dogs, and this might account, the authors think, for the difference. What is of special interest in their report is the observation that

* The form of this statement begs a very important question, to be discussed later.

"Consciousness was lost during the entire period of application of the current. . . . No patient complained of any unpleasant sensations during the electro-narcosis." Very dim memory was retained by some patients of the late or recovery stages. The treatment was sometimes maintained for as long as 30 minutes at a stretch. On termination there was a "prompt and speedy return of consciousness."

Reference has already been made to the findings of Gualtierotti, Martini and Marzorati (1942) in the context of spinal anaesthesia. In the majority of their studies these workers applied the Leduc-type (which they designate "Greek") current at the head either directly to the exposed brain, or by means of external electrodes, in cats, dogs and man. They categorically declare their confirmation of the original work of Leduc, with the exception of the question of the optimum frequency of interruption of the current, which they repeatedly affirm is at 280 cycles/sec., variations of as little as 15 cycles/sec. (approximately 5 per cent.) in either direction having a markedly reduced efficacy. This conclusion finds no representation elsewhere in the literature, either in respect of the frequency or the existence of so narrow an effective frequency-band (*cf.* van Harreveld *et al.* below). Their technique of application also differed from that employed by other workers, since they applied the current intermittently, for 30 seconds followed by 30 seconds withdrawal, and so on, to a maximum of 5 applications.* The reason for this practice is not given, but was presumably necessitated by their concomitant studies of the electro-encephalographic patterns which resulted. This team is the first to have invoked the electro-encephalogram for the (objective) study of the effects of the current on brain-function, and they describe, with reproductions, modifications of the normal encephalogram characterized sometimes by a complex sequence in time, and by representative slow waves and complete electric silence, likened to the phenomena in sleep and ordinary anaesthesia. It would appear that they have regularly succeeded in inducing states of true narcosis and anaesthesia, durable for hours, in both animals and man. No adverse effects or sequelae are described.

TRUE AND SPURIOUS ELECTRIC ANAESTHESIA.

That electric anaesthesia is a realizable possibility must be considered proven, but there has been acute controversy on the requisite conditions, and some of the comparatively recent literature even contains categorical denials of its existence and, indeed, its possibility. It is contended in these quarters that animals under the influence of electric current may be in a *nightmare state* wherein consciousness is maintained but motor paralysis prevents their evincing any movement or response to whatever stimulus, in very close analogy with the curarized state. Nor is the evidence by which this contention has been nourished by any means negligible. Regensberger (*op. cit.*) states the case clearly in his quotation of the remarks of a "Professor at North-Western University": "He stated that the conditions observed might be indicative

* This technique has representation elsewhere only in the studies of Leduc, who describes "cataleptic states" as a result of similar applications at 30-60 second intervals.

of consciousness, or they might simply denote lack of control of the muscles with full possession of the sensations In consequence, the condition observed might be merely a temporary paralysis, with the animal retaining full sensibility to pain. The hog cannot squeal because the throat muscles will not respond, and it cannot run or walk because the muscles are out of control, but it may be aware of all that is going on." It would appear that this was Dr. A. C. Ivy, whose subsequent work on dogs, and his conclusions, have already been mentioned. Hertz (1933) of the Rothschild Hospital, Paris, may now be quoted in the same context (the electric stunning of swine): "En réalité, l'animal est stupéfié, car la phase stupeur précède la phase d'électrocution; c'est un cochon stupéfié, mais ce n'est pas un cochon anesthésié. Le bénéfice est certain pour les spectateurs émotifs, il est nul pour le cochon."

Hertz speaks on the authority of his own very interesting experiments in this connection. In general, however, there has been a lamentable lack of serious endeavour to clarify this fundamental issue (of the state of consciousness) by the experimental method. Moreover, in scrutinising the literature on both sides it is impossible not to suspect that the thinking is sometimes guided wishfully.

Thus Anthony (1932), in the context of stunning at abattoirs, quotes numerous authorities who have given it as their opinion that the animals are unconscious. This carries quite rightly negligible weight with the opposition, who can produce experimental evidence in the reverse sense.

Müller (1932) in a vociferous defence of the method of electric stunning, argues by analogy from human epilepsy, and by a number of stretched analogies from experimental work in this and other connections, he concludes that unconsciousness is determined in both cases by cerebral anaemia. "I should not speak in favour of electrical stunning for the purpose of humane slaughter if the complete unconsciousness and insensitivity of the animals so treated were not an actual fact . . . doubts merely denote lack of biological knowledge of the subject."

Roos and Koopmans (1934, 1936) who enter the lists against Professor Müller, sufficiently indicate their opinion by their invariable use of the term "so-called electric stunning." They rightly decry all argument by analogy between chemical anaesthesia and the electrically induced condition, and by physiological experiments (1936) demonstrate that absence of the eye-reflexes is no criterion of the state of consciousness in the electrically treated animal, since the effector side of the reflex-arc is out of action. The same, they argue, must be true of all the reflexes.

Zimmern (1933), in an address to the Société de Pathologie Comparée, repudiates the entire project of electric anaesthesia. His views are largely based on experimental work conducted by himself in 1903, after a visit to Leduc's laboratory. He declares the anaesthesia mythical and the procedure actually dangerous (deaths in 1 in 4 of his experimental dogs). "Nous avons en effet été amenés à conclure que le sommeil électrique n'existe pas, et que l'inhibition provoquée par les courants de Leduc doit être interprétée non pas comme sommeil mais comme manifestation de la série comitiale. . . ."

Ainsi s'écroule tout espoir de l'adapter à la narcose chirurgicale. Ses dangers du reste suffiraient à l'interdire."

Stief (1933) has concluded from his experiments that "Electro-narcosis is not a narcosis proper but a complex of various symptoms, as drowsiness, unconsciousness, partial loss of tonus, catalepsy and stupor." He also records haemorrhages at the base of the brain and in the ventricles, and concludes that Leduc's current (which he says is conducted mainly by the cerebro-spinal fluid) is relatively dangerous.

Hertz (1933) conducted experiments of considerable import, on dogs and on human patients, using the Leduc current. The objective phenomena in both dogs and man were the same, and in his own words, "identique à ceux que Leduc et Roubinovitch ont décrits." To the observer, complete anaesthesia resulted, with steady respirations, relaxation, etc., under which (in the dogs) abdominal and other operations were successfully performed. "Nous avons été d'abord émerveillés par l'anesthésie apparente complète." It is noteworthy that Hertz does not seem to have found the method in any sense dangerous, as did Zimmern. He records no fatalities, or adverse consequences, and he proceeded to apply the method in a series of four human patients. Currents up to 25 mA. were used. All four subjects, while having the appearance of anaesthesia, are reported to have retained consciousness with various unpleasant features (sense of impending death, suffocation, etc.) and were able to relate where they had been pinched or pricked. Hertz concludes: "Il n'y a plus lieu à notre avis à discuter longuement. . . . Ce courant ne constitue en aucune façon un moyen de produire une anesthésie électrique comme cela a été dit par nos devanciers." He ends with a statement that similar current was applied to the limbs with a view to inducing regional anaesthesia, with completely negative results, failing to confirm Robinovitch and Kalendaroff (q.v.).

Finally, Hume (1936) and others have published data collected in respect of electric accidents, where the subjective experience of those concerned proves that unconsciousness is by no means a necessary consequence of contact with sources of even high-voltage electric power, and that where consciousness is retained the experience may be anything from unpleasant to agonizing. Naturally, a great variety of electric and physiological conditions are here concerned.

ELECTRO-CONVULSANT THERAPY.

This procedure, now in regular use in psychiatry, has so close a bearing on much that is at issue here, that brief reference to it is called for.

Technique.—50-cycle sine-wave A.C. at about 100 V. is applied for 0.1 to 0.5 seconds between electrodes strapped to the temples. The resultant current across the head is something of the order of 0.5 amp. r.m.s. The voltage requisite in each individual case can only be determined by trial. Where unusual resistance leads to an inadequate magnitude of current, a stunning shock (without convulsions) results. A summation of stimuli also is essential for the production of convulsions: a single pulse of whatever strength is inadequate and stuns only (Hemphill and Grey Walter (1941)).

This procedure differs electrically from that at abattoirs in that for the latter a long application with lower voltage is the rule.

The information derived from this practice and relevant to the present topic is as follows :

(1) The technique is simple.

(2) Memory of the shock is nil ; memory of the preliminaries are faint and " fade like a dream " (Fleming, Golla and Grey Walter (1939)).

(3) Fractures are now extremely rare with the improved technique (e.g. Hemphill and Grey Walter (1941) record more than 2,000 convulsions in more than 200 patients with no instance of fracture).

(4) Where a stunning shock only is inadvertently administered, immediate repetitions are practised in the hope of inducing convulsions. Batt (1943) employed in an exceptional case 26 successive stunning shocks without mishap, and repeated shocks are now in use as an amplified therapeutic measure (Milligan (1946)).

(5) Age *per se* is no consideration. Hemphill records the treatment of a 3-year-old child and Fleming a woman of 84. This is of special interest in connection with the following observation of Clark and Tweed (1932). Referring to the electrothaler, they remark : " A suggestion has been made that the apparatus may be used to produce unconsciousness in animals for minor operations, but in view of the enormous strain on the circulatory system, the wisdom of this suggestion is doubtful." As the technique in question here is the same in every essential as that in man, this (purely theoretical) objection can hardly be sustained.

(6) As is well established, for some time after treatment, some of the most difficult patients are more tractable and co-operative. In this context the observation of Clark and Wall (1934) in respect of rabbits and cats may also be noted : " There was some indication that the application of the current made the animal quieter and more docile for a considerable time afterwards, and Hess (1931) also reports this effect. . . ."

(7) Unconsciousness lasts for some minutes after the shock. Apart from the subjective and objective evidence, proof of the existence of a state of true surgical anaesthesia is afforded by the fact that where dislocations occur, as is exceptionally the case, they may and should be reduced immediately, " while the patient is still relaxed and unconscious." (Barrera and Kalinowsky ; Hemphill ; etc.).

Through the courtesy of medical authorities,* the writer has had opportunities of witnessing both the standard routine-use of E.C.T. in man, and also the prolonged treatment for producing electro-narcosis after the manner of the American workers. The absence of apprehension on the part of the patients having had previous treatments, and many of whom from the nature of their case, e.g. anxiety-neurosis, might most be expected to exhibit it, is as impressive as the expediency of the method and general consistency of the reactions.

* I am indebted respectively to Dr. W. Ogden, and to Dr. Thomas Beaton, for their kind invitations to witness these routines.

For the electro-narcosis the current is the usual 50-cycle A.C. from the mains, but the apparatus incorporates a constant-current device, this being its only significant special feature. In the American method, after an initial 30 seconds at high voltage the current is dropped to the point where respiration recommences, this being characterized by a marked stridor, which continues for the 9 or 10 minutes of the treatment. It is necessary slowly to raise the current over this period (manually) to maintain the state of the subject.

Patients go into the usual tonus, with slight opisthotonus; this is maintained throughout. There is consequently no convulsion as such. The arms are held in flexor tonus which tends continually to become stronger, with the effect of raising the hands towards the face. The abdomen is not unduly rigid, and cutaneous sensibility is absent. It is stated that there is always an absolute amnesia—no memory whatever of the treatment is retained. This general picture conforms to the sub-kinetic type of reaction described by van Harreveld, Wiersma *et al.**

SOME THEORETICAL AND TECHNICAL CONSIDERATIONS.

Methods in both chemical and electric anaesthesia have originated and developed largely empirically. Chemical anaesthesia has yet to be placed on a secure theoretical basis, and the position in respect of electro-narcosis is even more obscure.

(1) *The cerebral circulation.*

As has already been mentioned, the loss of consciousness has sometimes been ascribed to cerebral anaemia. In this context, Ivy and Barry (1931), observing the cerebral vessels before and during the application of the current, failed to note any change in their calibre. Clark and Wall (1934), however, noticed constriction of the pial vessels and slowing of the blood stream for some 3 seconds after the current was switched on. This was followed by dilatation of the vessels on switching off, or if the duration of application exceeded 10 seconds. Van Harreveld, Tyler and Wiersma (1943) cite Jacobi and Magnus (1925) to the effect that during electro-narcosis the pial vessels are markedly dilated. Their own conclusion, based on a study of arterio-venous differences, is that during electro-narcosis the cerebral blood-flow is increased. As this relates to prolonged narcosis it would be compatible with the phenomena observed by Clark and Wall.

Certainly there is little evidence here to support the "cerebral anaemia" hypothesis protagonized by Müller; the indications are that ischaemia does not occur. In any case, Clark and Wall in the same studies were unable to induce loss of consciousness by a stimulation of the cervical sympathetic, which resulted in a greater constriction of the pial vessels than they noted when their current was applied at the head. It is, however, believed that cerebral anoxia, in consequence of the general anoxaemia which follows the apnoea or dyspnoea, may play a part in determining the change over from the tonic

* The term "electro-narcosis" must be considered most inept in this special reference. Narcosis is a well-defined clinical entity, with hardly anything in common with the state under present consideration, which features neither muscular relaxation, nor a state from which the patient can be roused. "Prolonged electroplexy" would be a far more apposite term.

to the clonic state, and the ultimate decline of the latter (Hemphill and Grey Walter (1941)).

All the above workers are agreed that the effect on the blood-pressure is an initial brief fall followed by a marked rise, after which there is a slow decline to the normal level. That the fall in blood-pressure has no bearing on the loss of consciousness was demonstrated by stimulation of the vagus, which resulted in a parallel fall without unconsciousness (Ivy and Barry).

(2) *Physiological effects on the nervous system.*

According to Kovaks (1944), "the Leduc current . . . exhausts the sensory perceptions." Evidently this authority ascribes the effects to fatigue. Van Harreveld, Tyler and Wiersma (1943), on the other hand, while ascribing the results to stimulation, posit that it is by stimulation of the inhibitory mechanisms, a thesis materially supported by the Italian workers.

On *a priori* grounds, several possibilities seem to merit consideration, nor does it seem necessary to assume that only one mechanism is implicated. With interrupted D.C. or A.C. current these are

- (1) a maintained refractory state of the neurones ;
- (2) the reflex-fatigue of Sherrington ;
- (3) stimulation of inhibitory apparatus ;
- (4) failure of central integration ;
- (5) polarization effects.

Where continuous D.C. is concerned, (4) and (5) may be relevant, and it may be wondered whether electrotonus has some possible bearing on the case. These factors will be very briefly considered, *seriatim*.

(1) *Maintained refractory state.*—Where the period of the fluctuating current is shorter than the shortest refractory period of the nerves concerned, and provided that the strength of the stimuli is adequate, it may be anticipated that anything up to complete block of the natural pulses will result, since these arrive only at nerve that is refractory. Such an effect might be anticipated throughout the nervous system, but the affective consequences must be expected to differ at different levels, as will be noted below.

Where the peripheral nerves are concerned this could in itself account for the loss of normal sensation. But it merely substitutes artificial and extremely vigorous electrical stimulation of presumably all fibres, for the natural pulses generated by the receptors. While the latter and normal sensation are thus admittedly cut off, the substituted affective result may be any degree of sensation from faint tingling to unendurable pain, depending on the density and frequency of the current, and it is not easy to see how satisfactory local or regional anaesthesia can be obtained with pulsating current on any such basis, though Robinovitch and Kalendaroff both describe it. Current that could block the pain fibres by pre-emptive stimulation must be expected to cause pain, and of considerable degree. Some such difficulties are evident in Robinovitch's reports.

In contrast, none of the evidence, subjective or otherwise, indicates that the passage of considerably stronger currents than could be supported peri-

pherally, gives rise to any degree of pain as such at a higher level, as when traversing the spinal cord. At the level of the cerebrum such strong currents cause definite loss of consciousness, but the importance of the present consideration at this level is indeterminate. Other effects become possible at this level and in the spine.

(2) *Reflex fatigue*.—Thus with stimuli at the frequencies in question, it is difficult to believe that there will not be very rapidly induced at least some degree of reflex (synaptic) fatigue. Such fatigue, as both Sherrington and Adrian have pointed out, almost certainly plays a large part in the normal flux of sensation in consciousness. If, as seems probable, it obtains with the Leduc and other currents, this may be expected to lead to at least a general diminution in the intensity of the sensations,* or as Kovacs expresses it “an exhaustion of the sensory perceptions.” It would follow, if this is the dominating mechanism, that the decline in sensibility should be progressive, and measurable in time.

(3) *Stimulation of inhibitory mechanisms*.—The hypothesis of van Harreveld and Wiersma that the root mechanism is a maintained stimulation of the inhibitory centres does not seem to be readily compatible with those just considered: indeed they appear to be mutually exclusive. With these workers, however, the current was passed not in the length of the cord but across the head, and the mode of action here might be entirely different. At all events impressive support would appear to be lent to their particular theorem by the studies of the Italian workers.

As the American workers point out, such stimulation (of the inhibitory centres) may be expected to dominate the picture to the exclusion of simultaneous excitatory effects, in the same manner as, for instance, the knee-jerk is inhibited by ipsilateral pain. Moreover, several workers have commented on the hypnosis-like features of the narcosis; and cataleptic states were recognized and demonstrated by Leduc,† and have been described by others (Stief, van Harreveld, etc.). Inhibitory mechanisms might well be particularly important in the context of muscular relaxation and of the failure sometimes to obtain this (van Harreveld; Ross and Allen), which is believed by van Harreveld to be an idiosyncrasy of the individual.

This last conclusion is interesting and suggests that such idiosyncrasy might be equated with the relative development and functional state of the inhibitory centres in individuals. It cannot be doubted that these vary enormously, not only between individuals, but between breeds and species also. It is necessary only to compare the innate behaviour of the pointer breed of dog at work with that, for example, of a terrier in the same circumstances, to appreciate this innate difference in constitution.

Between species it may be anticipated that such animals for example as the hare, and to a less extent the rabbit, the rat, and indeed all species in which immobility is an important defence mechanism, possess inhibitory centres

* Such an attenuation of sensation was a major component of Leduc's personally recorded experience.

† As has been stated earlier, Leduc obtained this effect by applying several separate excitations at intervals of from 30 to 60 seconds.

that are very highly developed, and it is all such as these that should, in terms of the theory of inhibition, go most readily into the narcosis. Van Harreveld worked on dogs, and a study of the responses ("narcotic" and "kinetic" respectively) with reference to breed, temperament, age, etc., might be illuminating. It may be worth noticing in this connection that the human patients on whom he reports, and who generally exhibited sub-kinetic behaviour under the narcosis, are described as schizophrenics of long standing. He has concluded that this kind of reaction is the normal in man. The possibility that it might have been the consequence of a perhaps constitutional, and certainly well-established abnormality, can surely not be totally ignored.

(4) *Failure of central integration.*—Whatever may be the importance of the foregoing factors, it can hardly be doubted that wherever electric current of threshold strength traverses the central nervous system there will be failure, partial or complete, in the processes of integration. It is a matter of common experience that the conscious sensory pattern, including the apprehension of pain, is always to a large extent and may sometimes be entirely dependent on circumstances and the psychological desiderata. As Livingston (1943) emphasizes, pain is a subjective phenomenon consequent on highly complex integrative activities in the cord and higher centres, with a strong affective element. Where the currents in question are passing, the effect is presumably a continuous, indiscriminate, undifferentiated stimulation of all the nerve-elements, including those normally concerned with the correlation and integration of the whole complex of normal sensation. It seems not unreasonable to suppose that a state of integrative chaos (a true *delirium cordis*) may ensue, defying all interpretation at the higher levels: and that the net result, being sensorily indeterminate, may be relatively indifferent in consciousness.

(5) *Polarization effects.*—The extent and significance of polarization effects in the cord can hardly be assessed. Where, on the other hand, the brain is concerned, as in stunning and E.C.T., no electro-encephalogram is possible for 20 seconds after heavy current has passed; the brain becomes like a battery, with polarization effects long after (Fleming, Golla and Grey Walter (1939)). It is only to be expected in such circumstances that cerebration should be completely suspended and consciousness lost.

Before leaving this issue, it may be noted that Burge *et al.* (1936) state that the cortex is electro-negative in respect to the exposed sciatic nerve in the conscious animal, but that in chemical anaesthesia it becomes electro-positive. This polarity is freely reversible, and the phenomenon was observed with a number of anaesthetic agents, and with asphyxiation, haemorrhage, and the exhibition of CO₂. It is suggested by these workers that the brain behaves like a storage-battery, and that there is a threshold potential-difference which determines consciousness. While this is no doubt an over-simplification, their observations in respect of the polarity of the cortex may bear on the effects of heavy current on the cerebrum and consciousness, and the significance of the polarity of direct and pulsating current.

Anelectrotonus.—Whether electrotonus could play any part in the course of events with steady D.C. the writer is not qualified to say. It would appear to depend on whether currents of sufficient strength can pass. It is noteworthy

that the current strength required for D.C. to be physiologically effective is of a very high order as compared with that required for varying current. Thus Silver estimated it at 45 mA. for the dog, and 1 mA. per mm.² of cord, which would probably be fatal with I.D.C., while van Harreveld and his colleagues declare that in dogs "even . . . 500 mA. maintained during the entire experiment causes the same symptoms and does not endanger life." These last workers ascribe this difference in level for D.C. to its poor stimulating powers. It seems not impossible that a different mechanism may be involved.

Gualtierotti, Martini and Marzorati (1942) publish the only paper in the literature recording a direct experimental approach to the question of the physiological mechanisms concerned. Applying micro-electrodes to the exposed central nervous system they found that direct stimulation (with I.D.C.) in the region of the diencephalon (hypothalamus) constantly resulted in narcosis or anaesthesia. They claim moreover that separate centres exist effecting inhibition of function in the cerebrum, in the cerebellum, and as has already been mentioned, in the spine. The action of each centre is diffuse over its respective sphere—the entire anatomical unit is inhibited, as is demonstrated by electro-encephalograms, electro-cerebellograms, and electro-myelograms, as the case may be. The action is in no way reciprocal—stimulation at any other point results in nothing more than strictly and narrowly localized effects, while stimulation involving the pre-central motor-area resulted constantly in the motor activity to be expected. The mechanism in each instance they consider to be reflex.

The importance of these findings if they are confirmed needs no emphasis. They would seem to provide a complete explanation of the narcosis and seem fundamentally related to the now classical demonstration by Hess (1931) of a specific sleep-promoting centre similarly situated, no less than to the well-known narcoleptic consequence of tumours in the region of the third ventricle. It has to be pointed out, however, that the thesis that the effect results from clear-cut and direct inhibition by positive activity of the centres in question is not proven. There remains the alternative that the centres act not by the diffuse emission of afferent inhibitory stimuli, but by the total suppression of afferent stimuli, without which cortical activity may possibly suffer automatic extinction (Samson Wright (1947)). Indeed some additional weight is lent to this alternative in consideration of the fact that the currents used for these studies were of enormous magnitude (for currents applied direct to the central nervous system) such as might well be expected to dislocate the regional nuclear function rather than effect the hypothecated physiological stimulation, a consideration which may not be independent of the remarkably prolonged effects recorded.

(3) *The Influence of the form of current.*

For electro-narcosis (as opposed to electric stunning) the form of current used has been, almost without exception, the I.D.C. of Leduc, and in exceptional cases it has been D.C. With I.D.C. most workers report the best results with a current of pulse-frequency 100 per sec. and duration 1 to 3 msec.

The work of van Harreveld, Tyler and Wiersma already referred to included a study of the comparative effects of D.C., I.D.C. and A.C., and the influence of frequency and of duration of pulse. In all cases the current was passed across the head in dogs. The I.D.C. was thyatron-generated square-wave, observed and measured with an oscilloscope. Their findings are summarized below :

(1) For I.D.C.—(a) The strength-duration curve resembles that of peripheral nerve with a chronaxie that implicates the fast fibres (about 0.14 msec., rheobase about 100 mA.). (b) The pulse-duration is of small consequence down to 0.5 msec., when the threshold rises rapidly (the recurrence frequency was 120 per sec.). Pulse-duration has no influence on the course of events or symptoms.* (c) The interruption-rate is unimportant.† Above 1,000 per sec. there is some increase in threshold (ascribed to polarization effects), and above 500 per sec. the narcosis was commonly less tranquil.

(2) For A.C.—(a) The strength-frequency curve resembles that for peripheral nerves (para-resonance type). (b) All frequencies between 30 and 8,000 were effectual, but the narcosis was less tranquil between 500 and 2,000 cycles per sec. (c) The threshold minimum is about 100 cycles per sec., rising rapidly above this value (the threshold at 8,000 is 10 times the threshold at 100). (d) “The symptoms of en. [sic] produced with A.C. are identical with those produced with pulse current,” a conclusion discussed below.

(3) D.C. also is effectual, but it requires a considerably higher amperage, and recovery is slower.‡ During the flow of the current they observed torsion of the head towards the positive pole, and after some time a tendency to roll towards that side (galvanic vestibular reflex); on breaking circuit the effect was to the opposite side, a phenomenon explicable in terms of back E.M.F.

It must be remarked that the source of D.C. in the American experiments was the laboratory mains with an admitted ripple of 1.5 per cent., which was considered “physiologically unimportant.” At the lowest current passed this would entail variations of 2 or 3 mA. And at the highest, 500 mA., which was sometimes passed during the entire course of the narcosis, 7.5 mA. is involved. Robinovitch, as was stated earlier, is insistent that the source of current must be entirely steady for good results, and specifically vetoes the mains for the purpose, if only on account of the unreliability of their regulation. A variation of as little as 0.5 mA., she says, may suffice to cause trouble. This is a higher *proportion* of the current used by her than the proportion of ripple in the current used by van Harreveld, but it may be wondered whether some of the excitatory and other effects observed by the latter might not be due to this ripple.

The conclusion of these workers that sine-wave A.C. is physiologically the complete equivalent of I.D.C. of square wave-form is not a little surprising in view of the universally accepted belief that the square wave is a *sine qua*

* This conclusion is not universal; e.g. Ivy and Barry describe the best results with a pulse-duration of 3/10, a conclusion conforming well with that of the Italian workers.

† This result also is unsupported elsewhere. Most workers ascribe the best effects to a frequency of 100 msec. As has already been mentioned the Italian school insist that 280 msec. is uniquely superior.

‡ This conforms with the observations of Silver and Gerard.

non for good results, and indeed that goodness of the results will be proportionate to the rectilinearity of the wave-form (Robinovitch ; Ivy and Barry, etc.). Another surprising feature of their work is that their stated minimum current-strength for I.D.C. (some 100 mA.) is twice their minimum value for A.C. (approximately 50 mA.), for it is well-known that a sharp wave-front connotes far greater physiological activity than a smooth one, and as Hume (1935) has pointed out, the requisite current strengths for stunning with I.D.C. and A.C. are as 1:20. If the I.D.C. values are maximal,* and the A.C. are r.m.s., the difference does become less, but it is still the reverse of what might be anticipated.

The American observations on electro-narcosis, however, are thrown out of line with the rest by the use of (a) unusually high current (b) traversing the head only, and (c) maintained after an initial stunning current some 6 times greater, passed for 30 seconds. This last feature complicates the picture since "it is . . . possible to abolish the polarizing elements with strong current and to show that they require some hours to recover their properties" (Grey Walter).

In conclusion the work of Dénier (1938) requires mention. He has concluded that A.C. is rectified by passage through the tissues, giving an effect the equivalent of D.C. pulses, "which are probably more effective than A.C. in producing and sustaining either excitation or depression." Dénier is also quoted to the effect that the chief component of the impedance offered to the passage of current is the capacitative component in the impedance of the skin. The resistive component may thus be short-circuited by the use of higher frequencies. He states that the contractures resulting with low-frequency I.D.C. can be avoided by the use of higher frequency of period 1.5 msec. and a pulse-duration of 15 to 25 microseconds.

POSSIBLE DANGERS.

(1) *Damage to the central nervous system.*—Although the currents concerned in stunning in E.C.T., and for narcosis with the American workers, are nominally high (up to and even exceeding 1 amp. r.m.s.), the density of the current within the nervous tissues is, of course, much less. By reason of its vascularity the conductivity of bone is high, probably approaching that of saline, while that of the cerebro-spinal fluid is even better. In consequence of this and of dilution in the other tissues, the current-density in the brain is reduced in man at least 100-fold (Fleming, Golla and Grey Walter (1939)). In animals, where the brain is relatively smaller, the bones are more massive, and the temporalis and other muscles are interposed, the dilution will necessarily be greater.

Opinion is not decided as to the precise physical effects of the current on the nerve tissues (Barrera and Kalinowsky (1944)). Some observers can observe no histological abnormalities ; others describe a number of histological

* This is indicated by their measurement on the C.R.O. A major difficulty is created throughout the literature by the failure on the part of the majority of workers to specify their metric procedure. The quantitative data have little meaning otherwise, and where, as is usual, I.D.C. is concerned, the omission makes them valueless.

changes. The consensus of opinion would seem to be that such changes as may be produced are largely reversible, and clinical experience amply demonstrates that no lasting damage is brought about. Moore (1943) discussing maintenance therapy involving sometimes well over 100 treatments in man, observes: "Clinical observation shows no appreciable deterioration in personality or intelligence as a result of continued therapy." Milligan (1946) recording results with the "intensive method" in E.C.T., originated by Beaton, describes as many as 3 and 4 convulsions per day, and with an average voltage as high as 180 V., and daily repetitions. These were for the treatment of psychoneurosis, and excellent results, with case-discharge, are reported. If these data apply in man, the question of deleterious effects in animal patients can hardly arise.

(2) *Electrocution of the patient.*—There is, in even the well-educated public, and sometimes in the professions, a surprisingly potent streak of what can only be termed "electrophobia." Doubtless the association of ideas with the electric chair, and the occasional domestic accident, combined with misapprehension of the facts, are responsible. Indeed it is probable that this has played no small part in the strange neglect of the whole present topic.

Death by electrocution may result in three ways (d'Arsonval, quoted by Zimmern (1933); Curtis and Cole (1944)): (1) by direct searing action on the nerve-tissue, as with extremely high current (e.g. lightning); (2) from ventricular fibrillation (syncope); (3) by respiratory paralysis (suffocation). We are here only concerned with the last two of these. As regards ventricular fibrillation, this can only result where the current traverses the heart. According to Curtis and Cole (1944) the vulnerable moment is 0.1 seconds before ventricular diastole, when electrical currents as little as 25 mA. may institute the fibrillation, which is, of course, generally fatal, though normal action may sometimes be restored by an appropriate second shock. It is for this reason, of course, that alternating or interrupted current is commercially so much more dangerous than direct current, since the possibility of the stimulus coinciding with the susceptible moment in the cardiac cycle is so much greater. But this issue is not relevant to the question of the anaesthesia, since in no circumstances does the current-path lie across the myocardium (see, however, the discussion of the electrolethal chamber below).

The only danger pertinent to the question of anaesthesia is the third possibility, respiratory paralysis, which is in fact the commonest cause of electrical fatalities in man; and respiratory paralysis is a regular feature of the electro-narcosis—the current is increased to the point of respiratory arrest, and the narcosis-level lies at a value just below this, where the respirations are deep and regular.

It is well known to-day that the treatment for respiratory arrest of electrical origin is artificial respiration, which is successful in a high proportion of cases and even after very severe shocks. It is manifestly a risk which, if not entirely negligible, is present in considerably less degree than in the use of the ordinary chemical anaesthetics.

(3) *Danger to the operator.*—The possibility of danger to the person operating stunning or electro-narcotic apparatus may assume undue proportions in the

minds of the electrically innocent : it is in fact hardly real. With properly designed and constructed apparatus and the incorporation of common-sense safety devices it vanishes to zero.

(4) *Other effects.*—Zimmern has declared the Leduc current and technique highly dangerous on account of respiratory failure, and he also reported systemic effects, notably pulmonary haemorrhage and oedema, in his dogs.* Ross and Allen observed that in some of their dogs “the margin between the lethal voltage and the optimal voltage was very narrow,” and evidently care and discretion was needed in their case to arrive at the correct setting. This, however, is a generalization true for all anaesthetics, and the disastrous general effects described by Zimmern find no recognition elsewhere. They were not noticed by Ross and Allen. Ivy and Barry had no casualty in their total of 40 dogs, many receiving several treatments. Hertz felt justified in applying the currents to human patients (and Leduc to himself) without fatality. Van Harreveld and his colleagues employed heavy currents for as long as 30 minutes in dogs and man, this last involving a series of 9 patients and over 100 treatments, with no disaster. No doubt the danger of fatalities may be greater in the use of the Leduc-technique, where the current path is in the entire length of the C.N.S. and hence includes the respiratory centre. For transverse A.C. across the cerebrum, however, the clinical records of the routine use of E.C.T. in man provide overwhelming proof of the general safety of the procedure (see Kalinowsky and Hoch (1947)). It can only be concluded that the proper procedures are essentially safe, but that Zimmern's technique (and presumably also Stief's) was in some way at fault.

The only danger in these methods that seems to have any claim to recognition is that of bone-fractures. Though these have been virtually eliminated in man with the modern techniques of E.C.T., it has been accepted in the past that they are associated with powerful musculature (Hemphill and Grey Walter (1941)), although this has been contradicted elsewhere (Cook and Sands (1941)). They have, however, been the consequence of electric stunning in pigs (Anthony (1931)), usually involving the neck of the scapula or the thoracic vertebrae (as in man), though their incidence is given as a fraction of 1 per cent. (Anthony). The evidence on all sides indicates that their elimination is a matter of (a) complete freedom from restraint and (b) the correct electro-technology. There is no record of their occurrence in dogs or any of the other experimental animals used, but in large and powerful animals there is reason to anticipate this complication, which is present in any case in the horse with ordinary anaesthesia. The degree of risk, and the possibility, if it exists, of eliminating it by proper techniques of application in respect of the large animals, have yet to be determined.

GENERAL DISCUSSION OF ELECTRIC ANAESTHESIA : PRESENT USAGES AND THE POSSIBILITIES.

Electric current is already widely used as a general anaesthetic in pigs prior to their slaughter. It also has increasing use for the destruction of

* The most probable explanation of at least the oedema would be anoxia of the pulmonary endothelium, implying prolonged hypopnoea or other interference with the oxygen intake.

dogs and cats. It remains to examine its employment in these ways, and to consider briefly the possibilities of its more extensive use in the field of anaesthesia.

Consideration of the available evidence seems to justify the following conclusions :

(1) Electricity can be a potent anaesthetic agent.

(2) The conditions for its effective action in this sense are imperfectly understood, but for general anaesthesia two pre-requisites may be affirmed : the current must traverse the brain ; and it must be of sufficient magnitude.

(3) When the current fails to attain the strength required for anaesthesia general paralysis of the motor system antecedes an equivalent effect on the sensory side, and the objective phenomena may then have every resemblance to true general anaesthesia, whereas in reality a state obtains comparable in effect with curarization, of motor paralysis without, or with imperfect, suspension of sensation.

It follows immediately from the last conclusion that none of the standard objective tests of the state of consciousness applicable in general chemical anaesthesia is valid here. This fact must be recognized as entirely crucial to the whole issue. It means, for example, that none of the careful studies on animals recorded in the literature, where the persistence or otherwise of the various reflexes and the exhibition of painful stimuli have been the basis of the investigation, has any real relevance or significance. It means, moreover, that objective methods of an entirely different kind must be invoked, such for example as a study of the behaviour-patterns in animal-subjects in terms of their conditioned responses, or the use of electro-encephalography. The latter technique, while it is very reliable in such contexts, has the practical limitation that it is not applicable during the actual passage of the current.

Serious technical difficulties are, of course, implicit in any study of the state of mind and consciousness in animals. In the present context, direct observations under conditions of experiment of the subjective state in man are obviously the most decisive.

Electricity for the stunning of animals prior to slaughter.

The above considerations apply with full force in the use of electricity at the abattoir. The conclusion is therefore forced that we know very little indeed of the true requirements. Hume (1935, etc.) in several papers, has repeatedly questioned the validity of the criteria in use, but his thesis has so far received scant attention by the responsible authorities, though critical and unbiased examination of the position reveals every reason for his doubts of the adequacy (in the humane sense) of the sanctioned procedure.

It might be thought that the fact that the head of the animal is invariably in circuit affords a guarantee of the induction of unconsciousness. This, however, does not follow, for it is also requisite that the magnitude of the current passed shall be adequate. And it is a relevant fact that the voltage applied in pigs is considerably lower than that used in the (otherwise comparable) practice of E.C.T. in man. In man, voltages upwards of 100 are applied, whereas in the abattoir, voltages of the order of 70 are preferred,

since the higher rating (employed initially) was found to result in bone-fractures, which depreciate the value of the carcase on account of the consequent haemorrhage (Anthony (1932)). This important difference vitiates comparison between the two procedures, because even assuming that the electrical resistance is the same in man and the pig, the current density in the case of the pig is not less than 30 per cent. lower, and approaches the threshold value for effective action.

It is this lower voltage that necessitates the considerably longer application of the current in abattoir practice, in accordance with the strength-duration requirements discussed by Hemphill and Walter (1941), the formal practice being to retain the electrodes in position for some 10 seconds or more. This in itself must be considered a dubious recommendation from the humane angle, and it is evident from the reports of more than one of the official scientific adjudicators of the method that they consider the time factor both critically important, and liable in practice to receive too little respect (Dryer and Mitchell (1934)).

The present writer would go further, and say that this particular feature justifies condemnation of the procedure described. For if the above premises are admitted, and they are hardly controvertible, common-sense reasoning suffices to prove the method inhumane in a significant proportion of animals. Accepting for the sake of argument that the procedure followed provides adequate anaesthesia in the majority of pigs,* and recognizing also that the electric resistance of animals varies widely not only with size, but with the individual constitution of the animal, it is only necessary to correlate the requirements of the case with the general routine of the slaughterhouse to realize the inevitability of failure in a proportion of the pigs slaughtered. Now, the period of application of the electrodes is in actual practice left entirely to the discretion of the slaughterman. It follows inevitably (1) that this being a matter of judgement, the human element will determine a number of failures in all sizes and conditions of animal: (2) that from the nature of things, this time-period *will be computed in terms of the average animal*: (3) that human nature and commercial requirements being what they are, this period will furthermore tend towards the minimum, a tendency which will be aggravated by conditions of piece-work.

These formulations can lead to one, and only one, conclusion: that in the case of all animals having a higher resistance to the passage or action of the current than the average (low average), the humane requirements will not be met. These animals certainly suffer motor paralysis, but they are not anaesthetized.

Thus the remarks of Hertz in this connection (quoted earlier, p. 59) become entirely true; it is the curare-like action of the current that is being exploited in these subjects. And it is notable that this is done with full authoritative sanction, in spite of the fact that the Home Office (quite rightly)

* For humane requirements to be satisfied it is necessary that anaesthesia should not only be complete, but endure over the period of time required for slinging, sticking, and for the animal to bleed-out sufficiently. In the last context the fact that the animals are suspended head downwards during this time must be recognized as providing the maximum delay in loss of consciousness by the bleeding.

maintains the most rigorous control of the use of curare itself on animals, with a system of supervision that is, in effect, almost prohibitive of its use. It should further be emphasized that whereas curare *per se* has only motor-paralysant effects, sub-anaesthetic doses of electric current have the property both of effecting motor-paralysis and inflicting very considerable pain. Those practising E.C.T. on man are only too well aware of the unfortunate consequences of the accidental administration of inadequate electric dosage, which can permanently prejudice patients against further treatment. According to Golla, Grey Walter and Fleming (1940) the range of electric (ohmic) resistance in man, after the normal reduction in value which follows the passage of a few cycles of current, is approximately 33 per cent. of the average, so that the difference between the most and the least resistant subjects is as 2:1, to which is also to be added the variation in physiological susceptibility, (independent of ohmic resistance). Assuming, in the absence of specific data, that circumstances are comparable in the pig, it follows that the ohmically resistant subjects can receive as little as 50 per cent. of the current received by the least resistant, and 33 per cent. less than the average, who, as stated above, are themselves receiving only threshold values. The necessary inefficacy of the procedure in this proportion of animals is self-evident.

It requires only a visit to, and critical observation of, the actual course of events at any slaughterhouse where the electric method is in use to be convinced that the state of affairs realized in practice is exactly as described; nor is it possible to see how it could be otherwise with the practice described. It could even be argued that in many cases humane considerations would be better satisfied if the pigs were stuck with no electric preliminaries.*

If humane considerations are to be ignored and expediency is the sole consideration, the situation prevailing is eminently satisfactory. If, however, humane questions are to be admitted, the methods in use require the earliest possible revision.

Several of the modifications requisite have already been specified by Hume (*loc. cit.*). The procedure should provide by law for the following:

(1) An ammeter in series with the animals should be an integral part of the mechanism, both to monitor its performance, and to ensure that in all cases an adequate volume of current is passing. This fundamental requirement is never met, despite the well-known tendency of these machines to deteriorate in the constant use to which they are subject.

(2) *The period of application of the current should not in any circumstances be the responsibility of the slaughterman.* It should be controlled mechanically by a time-switch set to provide for anaesthetization, in terms not of the average animal, but of the most resistant, its operation to be signalled to the slaughterman by a pilot-lamp, and it should be illegal to operate the mechanism otherwise. This would be an innovation which would, of course, slow down the work by several seconds per pig, and its introduction would no doubt evoke corresponding commercial resistance.

* It should be borne in mind that the alternative method of slaughter by shooting with the humane-killer is unquestionably humane. But certain commercial objections have been raised against it.

(3) Provision for the passage of a constant level of current, independent of the resistance of the individual subject, and of a magnitude to be prescribed in the above terms, should properly be made. For this purpose the use of barretters, as suggested by Hume (*loc. cit.*) should serve the requirements of the particular case satisfactorily, at little expense.

The electrocution of dogs and cats.—Electrocution promises to supersede all other means for the destruction of dogs and cats, particularly at the large clinics and centres. It has great intrinsic advantages over other methods, being clean, economical to run, silent, bloodless, uniquely convenient, and operable by unskilled persons.

It might be thought that the electrocution of dogs and cats is germane to the topic of electric anaesthesia. Such, however, is not the present position, for no question of anaesthesia enters in. The avowed objective is not primarily unconsciousness, but death by heart-failure as the result of the institution of cardiac fibrillation. The animals are deposited in a chamber and the current passes either (1) from a metal collar around the neck through the body to a metal shackle secured to a hind leg; (2) from a metal neck-collar through to the four limbs which rest on a platform constituting the second electrode; (3) in the cat, the current is passed between the fore-limbs and hind-limbs, which rest on separate platforms constituting the two electrodes. The heads of the animals are in all cases out of circuit.

Hume has, in this context also, contributed several papers (1935, etc.) in which he questions the propriety of the general technique. He argues on the basis of the studies of Kouwenhoven and others (1930, etc.), and of Ferris, King, Spense and Williams (1936) on electrically induced cardiac fibrillation, that the requirements for fibrillation are strictly determinate, both electrically and physiologically, and that the guarantee that these requirements are met under the conditions obtaining in practice are inadequate.

This thesis is not without considerable scientific justification. It is equally certain that any method of destruction of dogs and cats, and having application in hundreds of thousands of cases per annum, demands the closest scrutiny if its humane principle can be called into the least question.

Fundamental to the issue are the facts that (1) contrary to public belief, unconsciousness is by no means implicit in the passage of the electric current through the body, as is amply demonstrated by the data presented in this paper, by the evidence adduced by Hume (1935) of subjective experience in cases of industrial accident, and by the observations of Zimmern (1933) and others in the same context; (2) that the passage of currents of any magnitude, where consciousness is not abolished, involve extreme degrees of pain, both by direct stimulation of the nerve-elements, and by reason of the muscular cramp which results. As Hume protests, unless the animals electrocuted suffer *immediate* syncope and extinction of consciousness in all cases, it must follow that they are being subjected to a preliminary period, of indeterminate length, of electrical agony.

Such a possibility (if indeed it is not a probability), must be considered a very disturbing one by any who have the least interest in the humane treatment of animals, and it is deplorable that it should have received so little serious

attention by those practising and protagonizing this method of destruction. No adequate attempt to clarify the issue by experiment has been made, and it therefore continues to remain in doubt, after nearly two decades of use involving several millions of animals. It has to be concluded that the convenience of the procedures in question has been a recommendation over-riding all other considerations.

It may be declared that it is in the cat that the method is most open to question. And the fact that the official prescription for destruction in these animals is in application of the current for 45 seconds, must be considered in itself a highly dubious and significant circumstance.

In the present writer's view, however, Hume's protestation is itself mistaken to the extent that it seeks to improve the technical provision for the induction of the ventricular fibrillation, because *it is the selection of this as the sole and root mechanism of death that is the fundamental fallacy.*

The first principle in euthanasia, and the attainable ideal, is that consciousness shall be instantaneously and with certainty abolished. Once this is reliably provided for, the actual mechanism whereby death is accomplished becomes a matter of free choice, to be decided in terms of reliability, convenience, economy and the aesthetic considerations. The present practices put the cart before the horse. They aim to arrest the heart and thus abolish consciousness, whereas the obviously proper objective is the exact reverse—to abolish consciousness and then arrest the heart.

All the scientific evidence affirms that the passage of a sufficiently heavy current through the brain connotes instantaneous unconsciousness. It is the deliberate exclusion of the heads and brains of the electrocuted animals from the pathway of the current that is the primary technical error. If this modification in the technique were made, no objection whatever to the electrocution could be sustained (with the proviso, as required at the abattoir, that an ammeter be supplied as an integral part of the machine, to establish in every case that the current passing is adequate*). In the dog this change would involve no more than the substitution of a simple adjustable muzzle for the neck-collar in present use. In the case of the cat, a complete revision of technique is demanded. The application of the current between pairs of limbs has no possible justification or desirability except that of its supreme convenience for the operator. The humane requirement is the provision of a platform constituting the live electrode covered by *thick* absorbent matting, properly wetted; and a head-collar of design permitting easy attachment and rapid, firm adjustment. This head-electrode should be earth-connected and be affixed after the animals have been placed in the chamber; and the chamber could be so constructed as to allow for the easy and comfortable protrusion of the animal's head only. In the very exceptional case where the animal's behaviour might make the proper application of the electrode to the head difficult, alternative methods of destruction should be invoked.

The proposed changes in technique would bring the electrocution of these

* This is again a regular omission, which it is difficult to understand, and a point repeatedly raised in Hume's papers. No electrical engineer would dream of issuing a machine for, e.g., commercial use, and in which the magnitude of the current was of critical importance, without incorporating a meter. Nor is the component expensive.

animals into line with that of penal execution in man, with which at present there is no legitimate analogy to be drawn.* It remains, however, to suggest in conclusion that the use of current at 2,000 volts pressure does not seem to have very clear indications, and may not be a true requirement in these small animals. Considerably increased direct cost is thereby incurred, and special precautions in respect of insulation (with the concomitant risk of breakdown) are necessitated. This voltage-level would appear to have been adopted in imitation of the practice in man. But it is the provision of a proper current-volume that is the sole issue at stake, and the voltage-rating as such is no guarantee of this. Indeed without good regulation a high voltage may well be inferior. On the other hand, the passage of excessively heavy current has itself certain contra-indications (Ferris *et al.* (1936)). Compromise with due regard to the several factors involved is called for, and it would seem improbable in the light of these that voltage anything in excess of 500 is necessary in the case of the dog and cat (provided always that the heads of the animals are in circuit.)

Electricity in Clinical Anaesthesia.—The possibilities of electricity as an anaesthetic in clinical work are implied in the review of the literature. It is in the sphere of agricultural veterinary activities that the subject seems to the writer to hold such remarkable promise, though it is impossible to ignore that a true electro-narcosis might prove to be the method of anaesthesia of the future, in man and animals alike.

The late Sir Frederick Hobday immediately foresaw the possibilities of the technique of simple stunning in general veterinary practice, and gave the ordinary "electro-lethal" trial for the induction of general anaesthesia for castration and herniotomy, with results that were on the whole satisfactory (1932, 1935), although his procedure was essentially of the crudest. These, however, are the only essays of the kind on record.

Major surgical operations under the Leduc current have been performed on animals. Robinovitch (1914) mentions the use of this current for laboratory surgery, and Frostig *et al.* (1944) refer to its similar usage by Tuffier and Jardrey (1907). Hertz (1933) performed operations on dogs in the course of his in-

* It may be of interest to refer for comparison to the technique of penal execution as practised in America, for there is no doubt that the official use of electricity as a means of execution in man carries for the public an implication that electrocution must therefore be essentially humane. This concept has as much foundation, in fact, as the equally general one that the term "lethal chamber" in some way connotes euthanasia. It is, of course, the precise manner in which these measures are employed that determines their humane propriety or otherwise.

The current is passed from a skull-cap through the head and trunk to the leg. The voltage applied is of the order of 2,000, and owing to the excellence of the electrode-contacts the resistance of the subject may be as low as 200 ohms. Thus current of the order of 10 amperes is involved (and a power of some 20 kilowatts). These conditions are maintained for 3 seconds, when the voltage is dropped to 500 for 57 seconds, the rationale of this being that it provides for a current of some 2-3 amperes, the presumptive optimum for the induction of fibrillation in man. The voltage is then restored to the 2,000 level and the cycle repeated. It is then again raised to the same level before switching off. At the conclusion of the operation the rectal temperature is stated to have risen to even 140 F., and the intra-cranial temperature approaches boiling-point.

These somewhat gruesome details are given because they indicate a technical ideal, and provide at the same time excellent contrast with the accepted practice in the case of animals. By inclusion of the head in circuit, instantaneous loss of consciousness is guaranteed. The optimum conditions for fibrillation are then provided.

vestigations, including a laparotomy. And it is here that it becomes necessary once again to emphasize the potential menace of the employment of electricity in animals without a complete knowledge of the requirements. For it is the unpleasant fact that in the same paper as Hertz records his surgery on dogs, he reports that his human subjects, undergoing similar electric treatment, were fully pain-conscious. It is universally certain that any general adoption of electric measures must be contingent on the availability of incontrovertible data as to the conditions under which they will and will not provide anaesthesia.

An interesting development in clinical neuro-surgery has recently come to notice. Freeman (1948) in introducing a new technique for prefrontal leucotomy in man, has also introduced electric shock as the anaesthetic of his choice for the operation. The patient receives current at 150 volts pressure across the head for 1 second. This results in a convulsion followed by surgical anaesthesia usually of several minutes duration, and ordinarily sufficient for the surgical interference. The treatment is applied at each of the two stages of operation.

The topical interest of this is great, for it will be noticed that the voltage applied is more than double that considered adequate for anaesthesia in the pig. Yet the writer has personally witnessed an operation on one patient of unusually low susceptibility to the current, in whom partial recovery of consciousness was manifested 90 seconds after the first shock, necessitating a second application. This provides evidence, as incontrovertible as it is gratuitous, of the validity of the arguments developed against present-day abattoir practice.

In corollary, there seems good reason to hope that improved electro-technology (perhaps with the invocation of principles not yet represented in the literature) may lead to the emergence of methods of electric anaesthesia of genuine practicability. These could have numerous and outstanding advantages over the existing chemical methods, such as induction with unexampled speed and facility, and comparably rapid reversibility. Not the least appeal of the whole conception lies in what, for want of a better term, may be styled the "physiological compatibility" of electricity, electric current being of course as integral and normal a component of the tissues in general and of the nervous system in particular, as oxygen is of the blood. Thus a complete absence of toxicity, and of the side-effects and after-effects of the chemical anaesthetics, might be realizable, and indeed seems already to have representation in the literature. A particular advantage of this would be the consequent extension of the method into laboratories where at present, for various reasons, the animal subjects may be denied the benefit of anaesthesia.

The phenomenon of amnesia, particularly of retrograde amnesia, must also be recognized as having great potential value in unusually temperamental animals, which may suffer permanent relative disability in consequence of even one unfortunate experience. The sum total of advantage and benefit accruing in at least the veterinary sphere, from the availability of methods of anaesthesia such as are envisaged, defies assessment.

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