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A HISTORY OF LOCAL ELECTRICAL ANALGESIA

KEVIN KANE AND ARTHUR TAUB

Section of Neurosurgery, Department of Surgery, Yale University School of Medicine, New Haven, Conn. 06510 (U.S.A.)

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INTRODUCTION

In recent years, the use of electrical stimulation for the production of local analgesia has been reintroduced in surgery[41], and in the treatment of chronic, intractable pain[66]. The mechanism of its action is somewhat controversial[6,33,44,56]. This paper presents a historical perspective of the process.

ELECTROGENIC FISH

Although a workable electrical apparatus was not truly developed until after the Renaissance, 'natural electricity' was in use therapeutically in Classical times. Its sources were certain marine and freshwater fish, especially *Torpedo marmorata* (torpedo ray, electric ray), *Malopterurus electricus* (electric or Nile catfish), and *Gymnotus electricus* (electric eel)[9,26,51,65,71]. The Nile catfish is prominently displayed in Egyptian tomb reliefs (Vth Dynasty, ca. B.C.E. 2750). The Greeks, however, provide the earliest known written record of an electric fish, the torpedo ray, known to them as 'narke', or the 'numbness producing' fish. Aristotle states: "The torpedo is known to cause a numbness even in human beings."[26] ('Torpedo', in this translation, is derived from the Latin, *torpere*, or 'sluggish'.) Both Pliny, in *Natural History*, and Plutarch, in *Morales*, refer to the 'numbing' effect of the ray[26].

Various parts of electric fish were long advocated as folk medicine to be taken orally. Scribonius Largus, *ca.* C.E. 46, advocated piscine 'electrotherapy' specifically for the relief of pain: "For any type of gout, a live black torpedo should, when pain begins, be placed under the feet. The patient must stand on a moist shore washed by the sea, and he should stay like this until his whole foot and leg, up to the knee, is numb. This takes away present pain and prevents pain from coming on if it has not already arisen. In this way Anteros, a freeman of Tiberius, was cured . . . Headache even if it is chronic and unbearable is taken away and remedied forever (sic) by a live black torpedo placed on the spot which is in pain, until the pain ceases. As soon as the numbness has been felt the remedy should be removed lest the ability to feel be taken from the part"[26,49].

This may be the earliest written reference to local electrical analgesia. The characteristics of the stimuli produced by electric fish are similar to those produced artificially for local electrical analgesia. They range in voltage from 1 to 350 V (40–50 V for the torpedo)[17]. The stimulus frequency may be divided into two groups: the 'fast' with a maximum of up to 1 kimp/sec, and the 'slow'. With the latter, the frequency band is narrow and generally reaches 200 imp/sec[17,28]. The number of impulses in a train varies from 100 to several thousand.

Scribonius does not indicate whether it is necessary to place the fish in proximity to the nerve trunks. He gives no indication of latency of the onset of the 'numbing' effect, but he does describe a gradual progression of the effect. Scribonius states further that 'numbness' may persist after contact is broken. No clear description of continuous accompanying paresthesias is noted.

Claudius Galen studied both living and dead electrical fish. The fish, when eaten, produced no relief, but when a live torpedo was applied to a patient suffering from headache, Galen noted that: ". . . it could be that this remedy is anodyne and could free the patient from pain as do other remedies which numb the senses: this I found to be so"[26]. The torpedo was used therapeutically, and not only for pain, by Marcellus Empiricus, Aetius of Amida, Alexander of Tralles, Paulus Aeginata, and others, until well into the nineteenth century. In non-Western cultures electric fish are still used for this purpose[26].

In the seventeenth century, Redi, Perrault, Richer, Borrelli and Lorenzini noted the 'numbness' produced by the torpedo[42,65]. Lorenzini described it as similar to "pain and numbness which one feeleth by a blow in the point of the elbow."[29] In the eighteenth century, many others noted the effects of the electric fish[7,25,26,42,67,70].

ELECTROSTATIC APPARATUS

For 150 years following Von Guericke's construction in 1650 of an electrostatic apparatus, a number of improvements were made in the charging of cylinders and spheres and in the manufacture of conductors. A major development came in 1745–6, when von Kleist, of Comin, and van Musschenbroek, of Leyden, developed a device that would both generate and store large quantities of charge. This was accomplished by the addition of a capacitor to the electrostatic machine. Nollet called this the 'Leyden jar', and used it in his experiments with animals and plants[9].

Before the development of the Leyden jar, Kratzenstein, in 1744, was one of the first to apply the 'artificial' electricity of electrostatic machines to medicine[9]. Walsh[67] and Cavendish[7] were probably the first to describe 'numbing' paresthesias produced by electrical machines.

John Wesley, the founder of Methodism, became an enthusiastic supporter of electrotherapy and fashioned his own electrostatic machine after observing a demonstration with a Leyden jar. He wrote a popular work, *The Desideratum*[68], which described the physical properties of electricity and its therapeutic applications. Wesley described a number of cases of pain relieved with this form of electricity, *e.g.*: "William Tyler, living at 'the Sun' in Longlane, Smithfield, was on March 9th last,

about three in the morning, seized with rheumatic pains, chiefly on his right side, so violently, that he was helpless as an infant, and was frequently constrained to shriek out, like a woman in labor. I came before nine. After the second shock he felt some change: after the third he was able to raise himself a little. After two more he rose and walked about the room, and before noon he was quite easy and well"[68].

Many were swept along with the new tide of electrotherapy. Electricity was accepted as useful therapy in paralysis, malcirculation of body fluids, irregular operation of the 'principle of life' and decreased perspiration[21]. Refutations, however, were not lacking. Van Marum repeatedly demonstrated that the supposed effects of electricity on pulse rate and perspiration, the bases for many claims of medical effectiveness, were not related to the stimulus alone[21].

THE ELECTRIC BATTERY

The development of the electrical 'pile', and the subsequent development of the induction apparatus provided further impetus for electromedical applications[13]. 'Voltaic' or 'galvanic', and 'faradic' currents were stronger and more easily modulated than was static electricity. Duchenne and Golding Bird championed the usefulness of such currents to medicine[5]; however, neither refers to analgesia produced by electricity in their lengthy texts. According to Colwell, despite the efforts of Duchenne and of Golding Bird, electrotherapy declined in medical respectability[9].

In 1858, Francis, a little known physician from Philadelphia, was the first to describe the relief of dental pain by electricity. He produced analgesia during a tooth extraction by the application of one electrode to the 'offending tooth' while another was held in the patient's hand[14,16,61].

Neef's 'induction apparatus', with its electromagnetic vibrator for interrupting current, and Stohrer's electromagnetic generator were significant contributions to the development of electricity[5,9]. The basic device of each could be used to produce interrupted, direct, or alternating current, depending on the modifications used. It is usually unclear from the medical electricity discussions of the time exactly what the characteristics of the instruments were, because of the many conceivable outputs, the often ambiguous terminology, and in most situations the supposed interchangeability of the currents.

Francis recommended either an 'ordinary galvanic battery' or an 'electric machine' as the source. He seems to have used a 'vibrating magnetic instrument' which produced an interrupted current[14]. He described 164 successful tooth extractions using 'galvanism', the majority of which resulted in 'no pain'. His 'controls', who received stimulation with the same set-up but with an open switch, did feel pain. Francis received a patent on May 25, 1858[62] (Fig. 1). A committee, appointed by the Pennsylvania Association of Dental Surgeons to study the use of electricity in dentistry, reported equivocal results, however, and did not recommend his apparatus for general use[31]. Nevertheless, his technique spread almost immediately throughout America to Europe[1–3,8,10–12,14,30,31,33,35,40,48,52,53,57,64,69].

Garratt was the first to use the technique in Boston in 1858–9[15,16]. He claimed

FRANCIS' GALVANIC

—AND—

ELECTRO-MAGNETIC PROCESS

—OF—

EXTRACTING TEETH WITHOUT PAIN.

Office rights to use this invention will be sold for $100, for the fourteen years for which the patents have been issued.

In order to make the payment easier, we will sell on the following condition:—

Right to use the invention for six months will be sold for $30—the purchaser to have the privilege of buying the right for the remainder of the time for which the patents have been issued, for $70 more.

The purchaser will be furnished with complete apparatus with instructions, accompanied by a correct lithograph, showing the operation of extracting a tooth by this process. Any further information may be had by addressing

JAMES J. CLARK, Assignee and Patentee.

CAUTION!

No person is authorized to sell rights, except they are furnished with a Letter of Attorney from me, recorded in the Patent Office, and having the Seal of the Patent Office thereto. JAMES J. CLARK.

☞Pamphlets with full information, and containing extracts from various journals relative to the use and success of this process, will be sent on application, *free of expense.*

JOHN T. TOLAND,

Agent for the West and South, No. 88 West Fourth St., Cincinnati, O.

Fig. 1. Francis' assignee promoting the use of Francis' 'Galvanic and electro-magnetic process of extracting teeth without pain'. Advertisement Section, *Dent. Rep.*, 1 (1858).

that he had experimented with effects of electricity on sensations occurring in surgery long before Francis[16]. Garratt, however, developed the clinical usefulness of the technique only after Francis had made his work public.

Garratt[15,16] (Fig. 2) recommended a commercially available generator, 'Mr. Hall's Apparatus', which was small, 'neat', and simple. It consisted of a Smee battery (sulfuric acid, zinc, and silver), an interrupting switch, an induction coil, a foot switch, and two electrodes. One electrode (the negative or 'stronger' pole) was connected to the neck, ear, or hand. The forceps were well insulated to the tips with rubber and varnish, so that only the teeth were stimulated. Garratt stated that the 'masking' of pain was of short duration, and consequently the tooth must be pulled within several seconds. He described 26 patients with dental pain who underwent 64 applications of electrodes to their teeth. At low current intensities, slight pain was usually

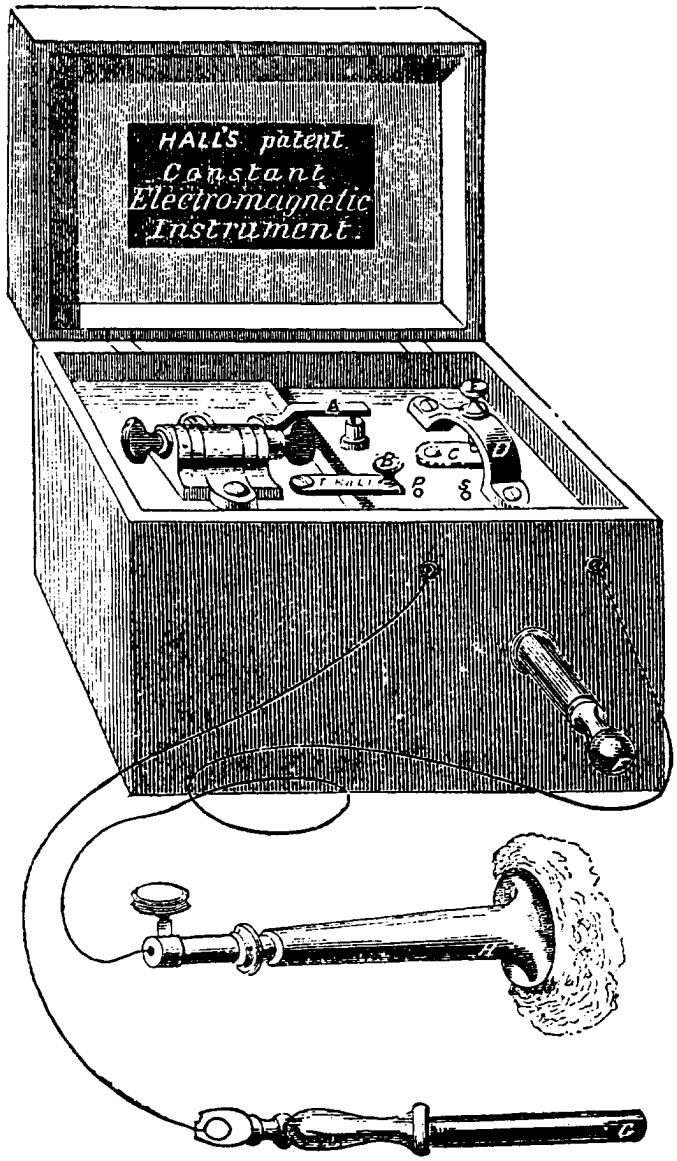

Fig. 2. The commercial 'magneto-electric machine' recommended by Garratt as an electroanesthetic current source, with pad and manual electrode. (From Garratt, A. C., *Electrophysiology and Electrotherapeutics*, Tricknor and Fields, Boston, 1860, p. 56.)

reported as resulting from the stimulus. At higher currents, either no pain or an unusual 'disquieting', 'tremulous', yet painless, sensation was reported. One-third of the patients felt no pain, another third felt relief of pre-existing pain with a mildly disagreeable sensation, and most of the rest felt moderate but bearable pain. A few felt a great deal of pain. Garratt also recommended the use of electrical treatment in peripheral neuralgias, hyperalgesias, tic douloureux, toothache and jawache. He stated that

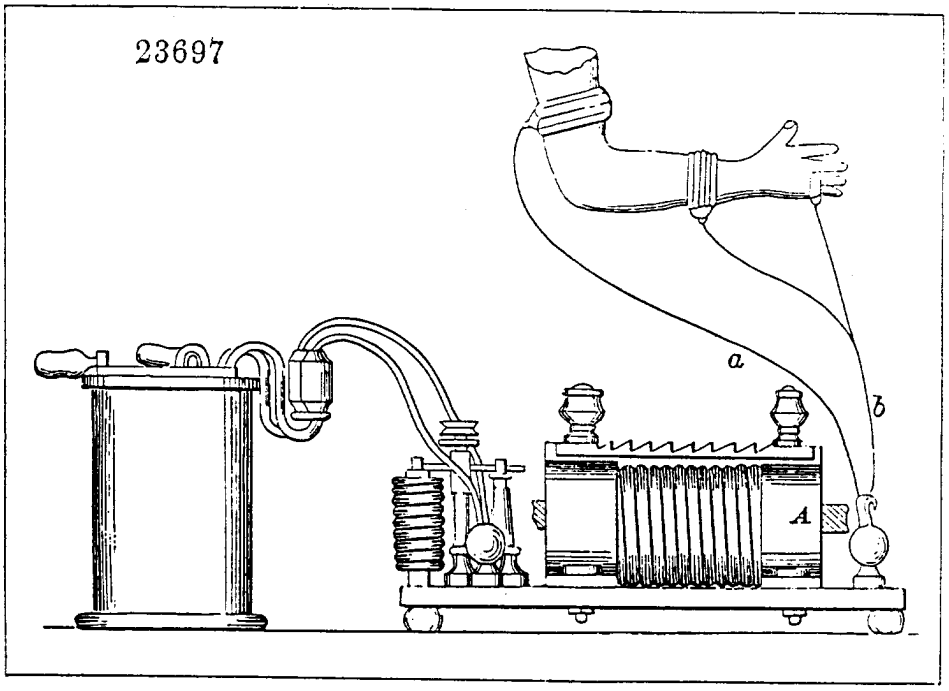

Fig. 3. Oliver's electroanesthetic apparatus in use, as illustrated in his patent. (From U.S. Patent Office Report, 1859.)

the electrodes should be placed on the edge of the painful site for 3–5 min with a 'just bearable' current. His experience with these other cases, however, was not recorded.

Another American, W. G. Oliver (Fig. 3), working in Buffalo in 1857–8, claimed independently to have discovered what he referred to as 'electrical anaesthesia'. A major legal battle developed over these two conflicting claims. Francis had obtained his patent (Fig. 4) first. Oliver was able to obtain one patent[35,62,63], but not without bitter argument and negotiation. Oliver used a magneto-electric apparatus to generate current. His device typically produced 'continuous current' except for the interruptions that were produced as the brushes changed commutators. Like Garratt, Oliver first applied 'electrical anesthesia' to dentistry, attaching the negative pole (because it was less disagreeable) to the forceps. Oliver introduced a 'vibrator' to interrupt the current and screwed 'the armature down to the smallest possible vibration' (the highest frequency). He reported '60% success' for relief of dental pain with the generator alone, and up to '98% success' with the generator plus vibrator[35].

Oliver also experimented with electrodes placed upon the limbs to produce surgically useful anesthesia. His perfected technique is described in an account of his second operation, performed by Hamilton on February 10, 1858, for the removal of an ulcer of the left leg of a male patient: "A wet bandage, about 3 inches wide, was wound around the leg a few inches above the ulcer, and a copper wire then wound over the bandage about 20 times and secured. A similar bandage and coil of wire was placed at the ankle. The positive pole was attached to the upper, and the negative to the lower

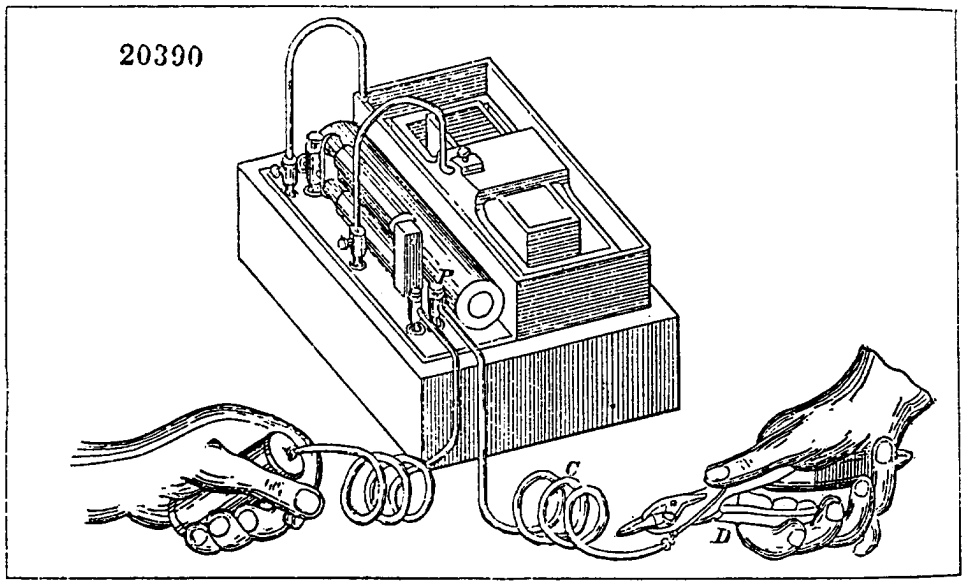

Fig. 4. Francis' electroanesthetic apparatus, as illustrated in his patent. (U.S. Patent Office Report, 1859.)

bandage. A gentle current was then established and increased until the muscles began to quiver, and he complained of severe pressure, as though the bandages were being tightened. The current was checked slightly, and kept steady for five minutes, and the operation commenced by the Professor cutting all around the edge of the diseased flesh, and then sliced the whole of it off, and removed every particle of diseased flesh. The patient was asked if he felt pain and he invariably answered, "No, only pressure at the bandages" . . .The flow of blood . . . was so profuse that the operator could not proceed, and he remarked that he should check it by dropping scalding water on to the parts, which he said was the most painful part of the operation[35]."

Unlike Garratt, Oliver reports here and elsewhere that electrical analgesia increased with time. The current used in his work was 'interrupted'. There was a definite time lag at the onset and in the decline of the 'anesthetic' effect. Paresthesias of pressure were produced at the site of the bandages. The procedure apparently failed to abolish temperature sense completely. Thompson[58] later found that cold and heat were the last sensations abolished by electroanesthetic currents. Oliver also recommended his technique for amputations and for childbirth. In obstetrics, he placed one wire around each ankle (negative pole), one at the waist (positive pole), and one around the neck (positive pole). The effect of this arrangement, Oliver believed, was to decrease pain without affecting uterine contractions.

In England, Althaus, a prominent electrotherapist, was the first to adopt and use the new 'electroanesthesia'[1]. In 1858, he applied 'interrupted' current transcutaneously to peripheral nerves. Unlike most others of this period, his technical descriptions are clear and complete. The subject in this case is Benjamin Richardson, who, ironically, was especially skeptical of its effectiveness. The previous month, Richardson had

published an article 'refuting' the anesthetic properties of electricity. (Using Leyden jars, he apparently did not use a rapidly interrupted current. Instead, he tested direct current and slow pulses, neither of which decreased pain[46,47].) Althaus describes his confrontation with Richardson: "...as he wished personally to experience the benumbing effect of the electric current applied to the trunk of a nerve. I consented to his request, and applied a rapidly interrupted current to Dr. R.'s ulnar nerve, placing one moistened conductor between the olecranon and the internal condyle, while the other conductor was placed in his hand. I began a current of low tension, such as was not powerful enough to produce contraction of the muscles animated by the ulnar nerve. After the current had acted for a few minutes, I increased the intensity, so that a strong flexion of the fourth and little finger was produced.The action of this current was at first painful to bear, and the pain continued to increase during the first few minutes of application; but it soon became less, so that I could further increase the intensity of the current, without causing much inconvenience to Dr. R., who became again gradually insensible to stronger shocks. The intensity of the current was then increased a third, fourth, and fifth time, and every additional increase was felt distinctly and immediately, but after a certain time the pain excited by very severe shocks was comparatively little. At last the normal sensibility of the ulnar nerve was so much diminished, that a current of such a high tension was borne without inconvenience by Dr. R., as would have been perfectly unendurable in the beginning of the experiment. Besides, Dr. R. mentioned a sensation of numbness in the tips of the fourth and little finger and that he did not feel the board upon which his fingers rested. The intensity of the current was then diminished, and Dr. R. was now quite insensible of shocks which had caused him much inconvenience previously. After the current had ceased to act, numbness was still perceived by Dr. R. in his arm for a certain time. It is therefore obvious that a direct reduction of sensibility of the ulnar nerve was accomplished by electricity, but although the intensity of the current was very high and the velocity of the intermittences very considerable, no complete anesthesia of the skin was produced, as the skin of the hand is not only animated by the ulnar, but also by the median and radial nerve[1]."

The experience of Drs. Althaus and Richardson is similar to that described by Campbell and Taub more than a century later[6,56].

Althaus had found that galvanic current, when applied for minutes, led to a decrease in sensation; however, the effect of a 'very great... velocity of intermittences' was more striking. He applied these techniques for the relief of neuralgia and found that in pathologic situations, analgesia was more effective and more readily attained than in normal situations, *i.e.*, within 5 or 6, instead of 15 min and with significant 'numbness' and analgesia[1]. Althaus claimed, like Garratt, that he had experimented with electrical anesthesia long before Francis had popularized it. Whether his claim was true or not, Althaus was the major proponent of electrical anesthesia in Britain and contributed a great deal to its dissemination.

The controversy created by the new technique led to a special conference of the College of Dentists of London on October 12, 1858, at which there was a general atmosphere of skepticism. Four statements were adopted at the conference: first,

electricity is not an anesthetic agent; second, it augments pain; third, electricity sometimes modifies the sensation produced; and lastly, when favorable results are produced, they are due to a 'diversion' and not a true insensibility[3].

A commission, headed by none other than Richardson, was then appointed by the dentists to examine the question further. As might be expected, Richardson's commission report strongly opposed the use of electricity to produce anesthesia[11]. Richardson described 65 patients tested with electricity during tooth extraction, 55 receiving 'intermittent' current of varied intensity and frequency, and 10 receiving continuous current. Polarity, strength of current, and types of instruments were varied in order to examine all possibly effective approaches. None produced any significant difference. Five patients were reported to have been definitely relieved. These results were discarded by the commission, because, they stated, the patients were 'in a state of syncope'. Those who received partial relief were dismissed because they had unusually easy extractions, 'diversions', or 'syncope more or less marked'. Most patients were reported to have felt no effect at all. In conclusion, the committee agreed unanimously that it had detected no local anesthetic effect. The issue is clouded by the fact that one commission member, Purland, later changed his opinion after a personal success in using electrical anesthesia in a tooth operation[11].

The evaluation of effectiveness of local electrical analgesia was further beclouded by an independent study of electrical anesthesia in 40 tooth extractions, the majority performed by Harding at University College Hospital, London[64]. The current was the same for all patients: an induced current. All patients reported numbing of the hand and then the arm when one electrode was held in the hand and the forceps were in place. The pain of extraction was abolished or decreased in all cases. In a control study on one patient, one tooth was removed with the current on, and one with the wire disconnected without his knowledge. Without the current, there was no decrease in pain, whereas with the current on, pain was eliminated.

In September 1858, 'electroanesthesia' in dentistry was introduced to France with the presentation of a paper by Francis, the American, describing 1500 'experiences', most of them favorable[3,40]. Articles were soon published in Germany[2] and in Italy[53]. 'Ordinary' electromagnetic generators were recommended by Francis, with one electrode in the subject's hand, and one on the insulated dental instrument. The current produced was apparently pulsatile, and its strength depended on the speed of the machine. Preterre and Magitot were appointed to study this new technique[3]. They reported three attempts to open abscesses with locally applied current. Two of the patients felt the usual operative pain as if no anesthetic were used, and the third felt no pain at all[3].

In 10 dental procedures, the results were variable. Four were described as successes (relief of pain), two as failures, two as 'doubtful', and two as negative controls. (In the latter, electrodes were placed on the ear instead of the tooth to see if there was a non-specific effect. There was not[48].) Robert, a member of the appointing commission, concluded from this work that, although he had some doubts, the effect was not one of 'diversion' but rather of true anesthesia or 'masking' (which he did not further define). Velpeau, on the other hand, concluded, "Qu'il n'y a pas d'anesthésie

produite, et qu'il y a quelque chose dans les dents américaines qui n'est pas comme dans les dents françaises" (anesthesia is not produced, and that there is something in American teeth which is not in French teeth)[48].

Another French surgeon, Morel-Lavallée, reported 6 successful tooth extractions performed with the aid of electric current. He also operated successfully on 5 other patients using locally applied current, for conditions that included an axillary abscess and a foreign body[33].

In subsequent years, the less careful, the less experienced, and the more cautious abandoned the technique of producing anesthesia by electricity because of variable and irreproducible results. Only certain interested workers, such as Althaus[1], Garratt[15], and Tripier[61] persisted in advocating its use. From his own experience in removing superficial abscesses and tumors, Tripier recommended expanded uses: passing a sound in the urethra ('faradization of the prostate'); stimulating the rectum to 'faradize' the uterus; removing teeth; and various peripheral disorders. Revillout used the current to relieve post-hysterectomy pain by applying one electrode to a moistened pad in the uterus and one to a pad on the hypogastrium. This was reported to be effective if applied before postoperative pain began[45].

With its loss of popularity, obscurity followed, and it was necessary for 'local electrical analgesia' to be 'discovered' (or rediscovered) many times after 1858. Guyot, in 1878, described the effects of an electric current which had been 'previously not reported'[19]. By placing electrodes on two fingers of one hand and on raising the current, he could prick deeply into the affected areas without pain. He also suggested that this procedure might be of use in operations, or in the treatment of neuralgias.

Araya, working in Chile in 1870–88, 'discovered' the local anesthetic effects of modified induced currents (using 4 electrodes instead of 2). He had been working with his 'new' discovery of general electroanesthesia* for several years before he realized its peripheral effects[39]. Pierron lists at least 11 articles related to electroanesthesia that were published in Chile soon after Araya's discovery[39]. Araya and his followers generally concentrated on the 'sleep-inducing' effects of cerebral and cervical electrodes. They also described and recommended the local application of current adjacent to nerves for operations, and in the area innervated for neuralgias[39].

THE TWENTIETH CENTURY

Beard and Rockwell[4] and Hutchinson[24] used the technique for neuralgia-like syndromes and acknowledged the efforts of earlier workers. Peterson[37,38] and later LeDuc[22,27] rediscovered local electroanesthesia on their own, without being aware of preceding studies. Peterson found that frequencies up to 2000 imp/sec were most

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* The term 'electroanesthesia' is confusing. Although it was first used in 1858 to denote electrical stimulation of peripheral nerves to cause a local analgesic effect, Araya[39], LeDuc[27], and others used electroanesthesia as well as 'electronarcosis' to refer to the state similar to 'sleep' or to general anesthesia that is produced by electrical stimulation of the brain or the cranium. Consequently, following Marinov, the modifier, 'local', is used in this paper to differentiate the two[32].

effective. Both strongly recommended the use of local electrical analgesia and experimented with its practical applications in surgery and in the relief of pain. In 1892, Peterson and Keneally, of the Thomas Edison Laboratory at Orange, N.J., described a successful surgical procedure: the lancing of a painful felon using percutaneous local electrical analgesia alone. The procedure was performed at the Nervous Department (sic) of the Vanderbilt Clinic in New York City, then under the direction of the neurologist Arnold Starr.

Robinovitch recommended local application of current in place of general anesthesia, even for major amputations[20]. She modified LeDuc's technique and used direct current with a revolving wheel interrupter. The frequency, as well as the duration of the shocks, could be varied by adjustable contacts. (This basic arrangement had been used by Aldini more than a century before[9].) She found that optimal levels for anesthesia were: 40 V, 40 mA peak, with pulse widths of about 10 msec, and frequencies of 100 imp/sec. With this arrangement, and with application of electrodes to appropriate nerves in the leg, several successful major lower limb amputations were performed in 1910 at St. Francis Hospital in Hartford[20].

Hughson[23] recommended the use of local electrical stimulation of the nerves as an anatomy teaching device to demonstrate the region of nerve innervation by producing a 'tingling' sensation. In 1928, Thompson and Inman, of the University of California at Berkeley, found that 'the cutaneous area supplied by a nerve may be rendered insensible to light touch by subjecting the nerve trunk to the influence of an alternating current.' Increasing current produced analgesia. The authors could determine the distribution of all the cutaneous peripheral nerves in the forearm of one individual by this means[60].

Shaw[50] also recognized, independently, the phenomenon of electrically produced hypesthesia. Using high intensity 'faradic' stimulation, he noted a raised threshold to noxious stimulation. Shaw, however, did not develop his interest further. Guenot[18] tested 11 subjects for the effect of 100 Hz electrical stimulation to the skin of the antecubital fossa on two-point discrimination. At a 'critical intensity' of about 1 mA, perceptible point distance began to rise and became 'linear' between 1.5 and 3.5 mA. As the current was reduced, he found a 'residual inhibition' in which a prolonged deficit occurred. Some of Guenot's subjects lost pain, touch, and pressure sense 'totally', but retained a feeling of 'heat' when strong pressure was applied to the anesthetized area. Guenot recommended the clinical use of this current but apparently did not employ it himself.

Following the work of Thompson and Inman[59], Paraf, in 1948, reported successful therapy in 127 patients with sciatic pain, lumbago, postherpetic neuralgia and tic douloureux[36]. Guenot, in 1953, described the work of Perrin, Bernard, LeGo, Presle, Wild and Prolest, all of whom used local and regional electroanesthesia[18]. Prolest experimented with 50–100 Hz monophasic and diphasic waves, which caused initial 'excitation' and paresthesias, but soon caused 'inhibition' and raised the sensory threshold to the current[43].

Local electrical analgesia as a phenomenon lay dormant until its republication by Wall and Sweet in 1967[66] under the impetus of investigations originally initiated to

study the effects of 'gating' peripheral input. In the interim, and unknown to the West, clinicians in the People's Republic of China introduced local electrical analgesia as part of the 'acupuncture anesthesia' process[41]. But that is another story[55].

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