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Electrical stimulation for the relief of pain*

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Introduction

Pain, as a symptom, usually indicates the presence of disease and with the resolution of the disease, so the pain clears. Unfortunately, in the presence of incurable disease, pain may persist. Malignant tumours constitute an important example of such disease. However, there also exist painful syndromes unassociated with malignancy, for which an explanation for the origin of the pain is still wanting. If these pains persist in spite of adequate pharmaceutical therapy either because of the severity of the pain or the side effects of medication, then surgery must be considered, to relieve the pain.

Persistent pain may therefore take the form of either that associated with malignancy (malignant persistent pain) or that unassociated with malignancy, but still persisting (benign persistent pain). These terms are by no means satisfactory, but in common usage.

For malignant persistent pain destructive surgery, to some part of the nervous system, especially the sensory pathways, is effective and appropriate *(1)*. The disadvantages of such surgery are the risks of excessive destruction precipitating incapacity, and the almost inevitable temporary nature of the relief, with eventual return of the pain.

These patients, however, often have considerable incapacity as a result of their disease and limited life expectancy and therefore these risks are perhaps more acceptable in order to provide a quick and major relief.

Patients with benign persistent pain, such as phantom limb pain, causalgic syndromes, pain associated with spondylosis or spinal degeneration or pain associated with primary disease of the central nervous system such as multiple sclerosis, tend to have less incapacity and a much greater, or even normal, life expectancy. Whilst destructive manoeuvres can prove effective in the short term, on repetition it is found that the risks of morbidity increase while the efficiency in relieving pain diminishes. Also, new, dysaesthetic pain syndromes, associated with the damage inflicted to the nervous system, can be precipitated and prove extremely refractory to treatment. Therefore, for benign persistent pains non destructive methods are to be tried. These methods would include psychotherapy, hypnotherapy, behavioural therapy, acupuncture and electrical stimulation. All these methods share a low risk of morbidity, but unfortunately also a relatively low efficiency.

Electrical stimulation

Electrical stimulation is not a new treatment for pain. The first report dates from the 1st century *(2)* when the electric torpedo fish was applied to the head of patients suffering chronic headaches. In passing, it is interesting to note the contemporary use of the word 'torpedo' to describe a shape, while its Latin origin, as with torpor, refers to the numbing or deadening effect of touching the fish, that is, the effect of sustaining an electrical shock. It is also interesting to note that these fish are capable of generating electricity up to 150 volts.

It will come as no surprise to learn that John Hunter's interest was fired by the phenomenon of spontaneous and apparently controlled generation of electricity and that in 1773 he performed dissections of the Torpedo fish with particular attention to their electric organs. These dissections are still on display in the Hunterian museum of the Royal College of Surgeons of England (Fig. 1). His dissections clearly showed that the electric organs were innervated by the massively hypertrophied, cranial segmental nerves that also supplied the first to the fourth gills.

It was in the 19th century that electrical stimulation reached its peak of popularity, when all respectable practitioners had beautifully constructed electrical stimulators that were manually operated (Fig. 2). The widespread application of this treatment to all forms of disease quickly lead to its disrepute and disuse.

In 1965 Melzack and Wall *(3)* propounded an explanation for the pain relieving effect of electrical stimulation. Basically they suggested that electrical stimulation of the sensitive, low threshold A fibres would interfere with or modulate the passage of impulses in the Ad and C fibres, normally thought to subserve pain. It was considered that this modulation occurred at the dorsal horn level in the spinal cord. This proposition had an immediate effect in regenerating an interest in the clinical application of electrical stimulationg to all parts of the nervous system.

TRANSCUTANEOUS ELECTRICAL (NEURAL) STIMULATION (TNS)

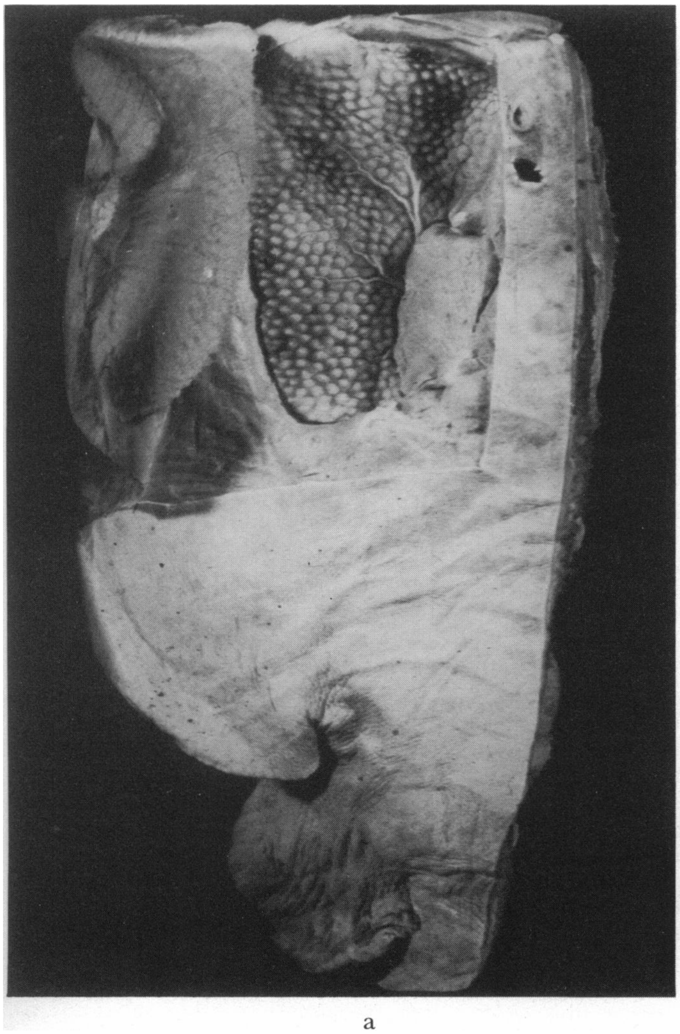
This is achieved by the placement of electrodes over the area of pain or over the peripheral nerve supplying this area. (Fig. 3). A flood of paraesthetic tingling in the area of pain is necessary for therapeutic effect, but even then it is not invariable for the pain to be masked or suppressed.

A range of responses is possible, from that of total suppression, even for periods of hours after stopping the stimulation, to no suppression or even aggravation of the pain.

The proportion of patients successfully treated with this form of electrical stimulation varies greatly with the perseverance and industry of the medical team and can be as high as two thirds *(4)*. Technical difficulties are common and may contribute to the undoubted reduction in the proportion maintaining long term relief. In a study of 79 patients seen at the Centre for Pain Relief, Walton Hospital, Liverpool in 1974, 22% obtained significant pain relief in the short term, but over a period of a year this had dropped to less than 10%. It is often physically difficult to maintain the electrical contact necessary to cover the whole area of pain with sensation. However, with patience and ingenuity it is possible, effectively, and over a prolonged period to treat, by this method, 'highly respectable' and distressing pain syndromes. I have two patients who have suffered phantom limb

* Based on a Hunterian Lecture given on 15th April 1981.

The Editor would welcome any comments on this paper by readers



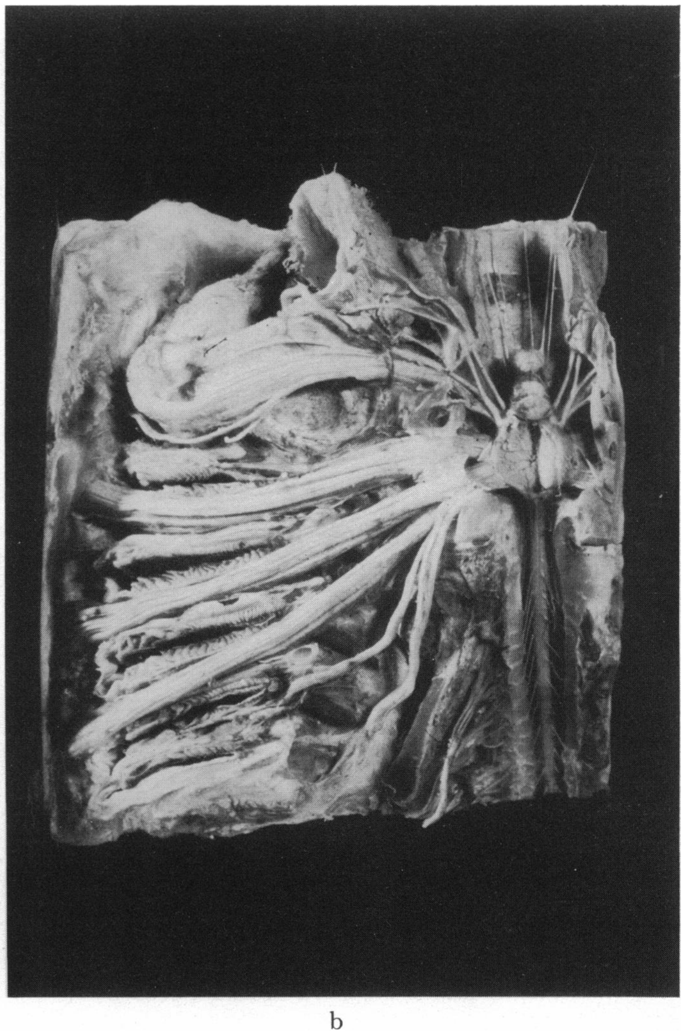


FIG. 1 Dissections of the Torpedo fish by John Hunter. Numbers 2175 and 2176 in the Hunterian Museum at the Royal College of Surgeons of England. (a) Superficial dissection of one of the pair of electric organs. (b) Deeper dissection to show the luxurious innervation from the lower cranial nerves.

pains for more than 25 years and who are now rendered totally comfortable by the regular use of TNS. Improvements in design of the electrodes, incorporating self adhesive and reusable materials will almost certainly further facilitate the prolonged use of TNS.

The form of TNS described is that now commonly called conventional TNS. The frequency of stimulation is high (between 33 and 250 Hertz) with low output and this results in an acceptable or even pleasant tingling sensation. Another form of TNS, now usually referred to as either electro-acupuncture or acupuncture-like TNS uses a different electrical programme of low frequency (2–3 Hertz) and high output, such that the sensation is harsh and often painful and is associated with contractions of underlying muscles.

The suitability of some patients, or pain syndromes, to one or other of these forms of TNS appears to be different and there is some evidence for different modes of action with acupuncture-like TNS, as its name implies, having a mode of action more like that of acupuncture and possibly involving endorphin systems *(5)*.

DORSAL COLUMN (SPINAL) STIMULATION (D.C.S.)

In order more effectively to cover widespread and especially bilateral pain the spinal cord has to be stimulated. The permanent maintenance of a percutaneous cable from the source of electricity, through the skin to the buried electrode, is not surgically acceptable because of the risk of infection along the track. An implantable electrode system is therefore necessary (Fig. 4). The most common involves an external power source acting as a transmitter or inducer of a current in a buried circuit. Circuits with their own power sources in the form of long life batteries, are also available and can provide prolonged stimulation with little need for external manipulation, sometimes a great asset in the more incapacitated patient.

The initial experience of indiscriminate spinal stimulation was again attended by poor results *(6)*. Quickly it was recognised that a process of selection or assessment was

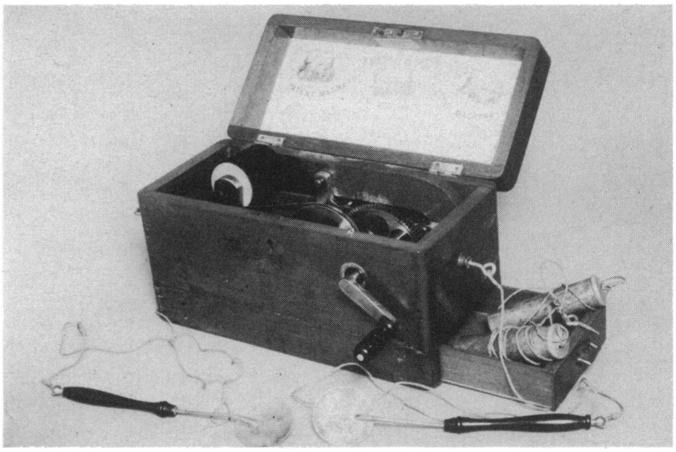


FIG. 2 19th Century 'Improved Magneto Electric Machine', kindly loaned by Mr. A C Brewer FRCS

FIG. 3 Modern transcutaneous electrical (neural) stimulator. Two electrode terminals. Hand control of output and frequency.

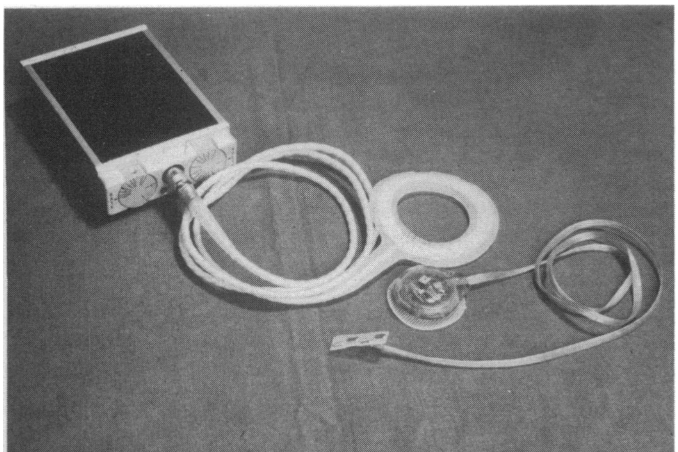


FIG. 4 Dorsal column electrical stimulator implant. Implantable circuit on the right. External transmitter with aerial, controlled by the patients, on the left.

essential. Our protocol for assessment is shown in Table 1, and is not totally comprehensive, but yet means weeks of careful in-patient surveillance. Much of the protocol is obvious, but essential if errors are not to be made. The part of the protocol under the subheading provocative stimulation is based on the thesis that electrical stimulation is acting as a form of counter irritation. The susceptibility of the pain to interference by other influences should help to predict the efficiency of an electrical implant in relieving pain. For all the influences or tests used, excellent relief is scored as 2,

TABLE I *Assessment protocol prior to stimulator implant*

Clinical
Pharmacological
Psychiatric
Psychological
Physiological
Sensory threshold
Cerebral evoked potential
Provocative stimulation
peripheral nerve (abrasion, t.n.s.)
segmental (acupuncture, hypertonic saline injection)
posterior column (percutaneous trial stimulation)

some relief as 1, no relief as 0 and if the pain is actually aggravated as X.

Trial electrical stimulation, either as TNS or percutaneous stimulation is clearly very important *(7)*, but neither, in practice, proves reliable enough, or easy enough, to be used in isolation. A decision to implant is therefore made based on an assessment of the influence of many or all of these test factors.

It is sometimes easy to predict that electrical stimulation will prove ineffective when the response to the tests are unequivocally all 0's or X's. It is often possible to recognise the very susceptible and therefore favourable pain syndromes when there is a high proportion of 2 ratings. Between these two extremes many patients appear to obtain some relief on some of the tests and their susceptibility is therefore not clearly defined. It is then, particularly, that psychiatric assessment may prove decisive with an emphasis on the question of whether partial relief of pain would significantly improve the patient's quality of life.

It has become clear that some of the tests have greater correlation with electrical stimulation than do others. Abrasion (vigorous rubbing) of the peripheral nerve supplying the area of pain, when this is possible, correlates well with the result of an electrical implant. The effect of injecting hypertonic saline (7.5%) into the interspinal ligaments at the segment of the pain, likewise, can have a profound effect on the pain and correlates well with likelihood of electrical stimulation relieving the pain. Conversely, the effect of traditional acupuncture appears not to correlate with the effect of electrical stimulation by implant. The predictive value of these manoeuvres has, of course, been gradually built up from the experience of early cases including the failures.

Other subjective and less certain influences can also be obtained from questioning the patient. It is well known that a great number of external factors are often implicated in aggravating or alleviating pain, such as the weather, temperature, mental stress or mental distraction, in addition to the more obvious effects of analgesics and alcohol. Correlations between these diverse factors and the possible effect of electrical stimulation, are less easy to determine, but local heat, aggravation by cold or wet weather and alleviation by mental distraction, tend to parallel a good response to electrical stimulation.

DORSAL COLUMN STIMULATOR IMPLANT

The original dorsal column stimulator (Fig. 4) was designed for open surgical implantation. A single level laminectomy is performed above the highest level of pain. The trimmed electrode plate is insinuated into a pocket excavated in the superficial layer of the dura. This superficial layer is then stitched over the buried electrode plate. The insulated electrical cable is passed subcutaneously from the site of laminectomy to the subcutaneous site for the receiver. The receiver is placed in a superficial subcutaneous pocket at a point convenient for the patient to reach, usually on the anterior abdominal or chest wall.

A more recent development has allowed the retention of the initial, percutaneous, test electrode, which is connected at a second operation to a subcutaneous receiver. This obviates the need for open surgical laminectomy and theoretically allows for a greater accuracy of placement. Unfortunately, this form of simple percutaneous electrode is liable to displacement with loss of effect. Further design modifications to the tip of these percutaneous electrodes will almost certainly improve their positional stability.

As has been mentioned, battery powered implants are also now available offering various degrees of versatility regarding output and frequency of stimulation. These parameters are varied by an external programmer.

DEEP BRAIN STIMULATOR IMPLANTATION

For those who do not respond to electrical stimulation to the peripheral nerve or spinal cord it is possible to stimulate higher structures in the nervous system. Technically the implant requires stereotactic facilities (Fig. 5) by which one or more electrodes can be passed to chosen targets. A percutaneous trial stimulation is essential and only if satisfactory relief is obtained is the percutaneous system converted to a permanent implant, again, with a subcutaneous receiver suitable for radiofrequency coupling (Fig. 6).

Stimulation to various points on the somatosensory pathway from the medial lemniscus, through the thalamus and to the internal capsule, can be undertaken and is based on animal and human electrophysiological studies extending back more than 20 years *(8)*. This form of stimulation tends to be reserved for pain syndromes associated with injury to the sensory system (de-afferentation syndromes). As with dorsal column stimulation, it is necessary to project paraesthesae into the area of the pain when stimulating this pathway.

Stimulation to deep central grey areas such as the periaqueductal grey (PAG) of the upper mid brain or the periventricular grey (PVG) adjacent to the walls of the third ventricle has evolved from studies into electro-anaesthesia by Reynolds *(9)*. This work was initially undertaken on the rat and later confirmed in other animal species *(10)* and finally applied to man by Richardson *(11)*.

Assessment of suitability for either of these forms of brain stimulation has, as yet, remained unsatisfactory, other than by percutaneous trials. It was hoped that an intravenous morphine injection would help predict suitability for deep central grey stimulation based on the awareness that these areas contained endogenous opiates. There is some evidence that this form of stimulation provokes the release of recognisable endogenous opiates *(12)*. In practice it has not proved as reliable as was hoped. Likewise it seemed that the challenging effect of an intravenous injection of naloxone, acting as an opiate antagonist, by provoking or exaggerating the pain, might again augur well for deep central grey stimulation. As in animal work, so in human studies, this drug is most unpredictable in its effect.

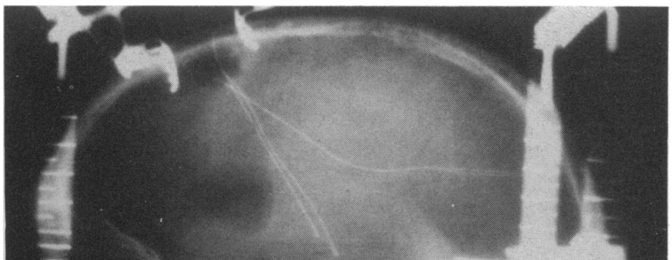


FIG. 5 Implantation of two bi-polar electrodes to deep brain targets using as guidance a stereotaxic head frame.

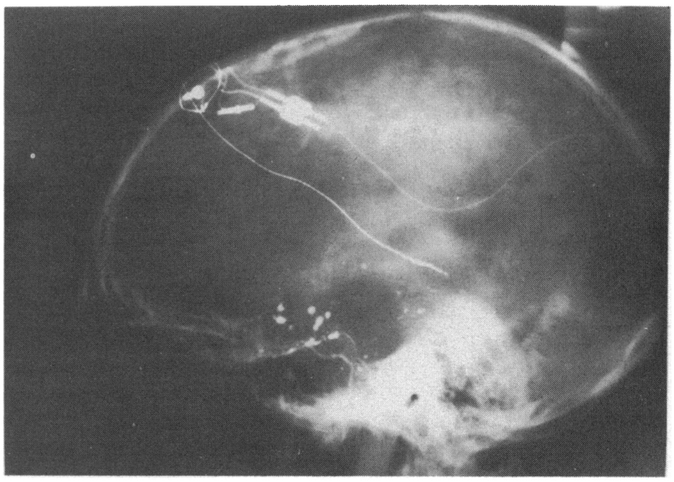


FIG. 6 A single bi-polar deep brain electrode connected under the scalp to insulated wires passing down subcutaneously to a receiver on the chest.

Results of electrical stimulator implants in Liverpool

Over the past 10 years, 120 patients have been investigated with a view to possible implantation of electrical stimulators. Of these, 15 were so effectively relieved of their pain by the trial TNS that this was maintained as the permanent treatment. Of the rest, 60 patients were implanted with 43 implants to the spinal cord, 3 to peripheral nerves and 15 to the brain. One patient had both brain and spinal implants.

The results from combined spinal and peripheral nerve stimulation showed that 23 patients obtained excellent relief of pain (grade 2); 19 some relief (grade 1) and 4 had no relief. These 4 total failures occurred in the first 15 patients implanted when the criteria for implantation were either non existent or uncertain. The majority of those patients who obtained only some relief of pain were predicted during assessment as being likely to have only partial relief. Four patients have gradually, over a period of years, required progressively less stimulation in order to remain comfortable. The best now requires to use his stimulator only in the depths of winter. The range of follow-up is from 3 months to 10 years with a mean of $4\frac{1}{2}$ years.

Fifteen patients have had a total of 27 implants to deep brain structures. The pain relief has not been impressive. A single patient has had excellent relief of pain for more than 1 year. Eight patients have obtained some relief of pain, but in only 7 of these did it appear to be sufficient to justify permanent implantation. It has to be emphasised that stimulator implant to the brain is reserved for those patients with severe pain ineffectively treated by medical means and when all reasonable physical means have been exhausted.

COMPLICATIONS OF STIMULATOR IMPLANT

There have been four infections requiring removal of the equipment, one of these being at the trial percutaneous stage. We have seen no spinal arachnoiditis, though many of the patients have shown gradual increase in the threshold for stimulation. Transmitter antennae regularly break and are easily replaced. Implant failures due to breakage of the cables or a leakage through the insulation are beginning to become a problem. Cable breakage is easily confirmed radiologically but insulation failure without cable breakage requires a more sophisticated electrical search. Repair of broken cables is achieved by the insertion of an extension with crimping of the wire contacts, while the outside insulation is reconstituted, using silicone plastic sleeves filled with silicone plastic adhesive. We have seen 4 such breakages.

MODE OF ACTION OF ELECTRICAL STIMULATION

We have assumed that electrical stimulation to the somatosensory pathway acts as a counter irritant, in some way, masking the pain when paraesthesae are projected into the painful area. Melzack and Wall's gate control theory of modulation *(3)* does not conflict with this idea. The unequivocal experience that some patients obtain pain relief extending for hours or even days following a limited period of stimulation, does not easily fit any electrophysiological hypothesis. This would tend to require a more massive, and possibly biochemical change in the background environment. To date no such definite correlation has been determined.

A considerable interest exists in the effectiveness of brain stimulation to the deep central grey areas and the generation of specific chemicals, some of which can be recovered from the CSF *(12)*. The initial results, fitting as they seemed, so appropriately with the discovery of endogenous opiates, have not really proved reproducible. It is quite likely that this problem is still a matter of the diverse and incompatible methods of neurochemical measurement, used by different investigators.

Summary and conclusions

Electrical stimulation can relieve some severe and otherwise persisting pains. At its best it can be associated with either a gradual reduction in the pain or an increased ability by the patient to control his suffering. It seems particularly appropriate for use in the field of benign persistent pain.

Equipment design and materials, particularly for implantable circuits, are not perfect. Movement towards percutaneous implantation, obviating the need for open operation, seems progressively more popular. Any unit or group using this form of treatment, must be prepared to provide major technical facilities, both in the form of people and equipment in order to cater for the many purely technical problems that occur.

A great deal of knowledge both neurophysiological and neurochemical seems to be accruing from the clinical use of electrical stimulation. We would do well to take advantage of this opportunity, in the hope that it might lead us to a better understanding of the functioning of the nervous system. This consideration remarkably parallels an observation made by John Hunter in his presentation to the Royal Society in 1773 *(13)* which anticipated the realisation of the part played by electricity in the function of nerves. Following his description of the extraordinary innervation of the electric organs of the Torpedo fish, he wrote:

'How far this may be connected with the power of the nerves in general, or how far it may lead to an explanation of their operations, time and future discoveries alone can fully determine.'

John Hunter (1773)

References

1 Miles J. Surgery for the relief of pain. In: S. Lipton, ed. Persistent Pain Vol. I London: Academic Press, 1977; 129–48.
2 Kelleway P. The part played by electric fish in the early history of bio-electricity and electrotherapy. Bull Hist Med 1946;20:112–16.
3 Melzack R, Wall PD. Pain mechanisms. A new theory. Science 1965;150:971–9.
4 Loeser JD, Black RC, Christman A. Relief of pain by transcutaneous stimulation. J Neurosurg 1975;43:308–14.
5 Sjölund BH, Terenius L, Eriksson MBE. Increased cerebrospinal fluid levels of endorphins after electro-acupuncture. Acta Physiol Scand 1977;100:382–4.
6 Nashold BS, Friedman H. Dorsal column stimulation for control of pain. J Neurosurg 1972;30:590–7.
7 Hosobuchi Y, Adams JE, Weinstein PR. Preliminary percutaneous dorsal column stimulation prior to permanent implantation. J Neurosurg 1972;37:242–5.
8 Olds J, Milner B. Positive reinforcement produced by electrical stimulation of the septal area and other regions of the rat brain. J Comp Physiol Psychol 1954;47:419–32.
9 Reynolds DV. Surgery in the rat during electrical analgesia by focal brain stimulation. Science 1969;164:444–5.
10 Lieberskind JC, Guilbaud G, Besson JM, Oliveras JL. Analgesia from electrical stimulation of the periaquiductal grey matter in the cat: Behavioural observations and inhibitory effects in spinal cord interneurones. Brain Res 1973;50:44–460.
11 Richardson DE, Akil H. Pain reduction by electrical brain stimulation in man. J Neurosurg 1977;47:178–94.
12 Hosobuchi Y, Rossier J, Bloom FE, Guillemin. Stimulation of human periaqueductal gray for pain relief increases immuno reactive B-Endorphin in ventricular fluid. Science 1979;203: 279–84.
13 Hunter J, Anatomical Observations on the Torpedo Fish. Phil Trans Roy Soc 1773;63:481–5.