Transcutaneous Electrical Nerve Stimulation for the Relief of Pain

John W Thompson

Summary
Electroanalgesia has been practised since ancient times, but had not gained widespread popularity with patients until the advent of transcutaneous electrical nerve stimulators in the 1970s. These electrical stimulator units have now been developed into highly effective relievers of pain, offering significant long term benefit to around 40% of chronic pain sufferers. A number of variations to the units have been designed to improve the efficacy of stimulation, however there remain 3 basic forms: continuous, pulsed and acupuncture-like. Before rejecting the method as ineffective for any patient, it is important to have an adequate trial of treatment of at least a fortnight during which all forms of available stimulation are tried, with electrodes placed in a variety of positions on the skin for a minimum of an hour at a time. Failure is generally due to lack of perseverance or unrealistic expectations.

Key Words
Electroanalgesia, Pain relief, TENS

Introduction
Electrical stimulation of the human body for therapeutic purposes (electrotherapy) has been employed in various forms since early times (Table 1). It has been shown that pain, and in particular chronic pain, can be relieved by electrical stimulation of appropriate peripheral nerves or selected areas of spinal cord or brain (Electroanalgesia).

Transcutaneous electrical nerve stimulation (TENS) is the simplest method by which a patient can utilise the analgesic properties of electricity. It is applied to the skin via a pair of stimulating electrodes which are connected to a portable battery-operated transistorised stimulator. TENS has been used for many different types of pain including those associated with peripheral nerve damage, sciatica, arthritis, cancer, amputation, surgical operations and dental problems.

The results of a number of studies indicate that there is a significant and therapeutically useful analgesic response to TENS. As with medication, there is a placebo response to TENS and this factor contributes to the initial, but transient, analgesic effect in response to electrical stimulation seen with some patients. Thus the response of a group of patients to TENS may be as high as 70-80% during the first week, but this falls to about 40% at the end of the first month and to about 35% at the end of the first year (1,3,4,7). Nevertheless, there is a hard core of patients for whom TENS offers significant and continued pain relief and where medication has often failed to help or where there are no alternatives, with the possible exception of ablative procedures.

Equipment for TENS
Stimulator
This is a transistorised, battery operated, pulse

Table 1
SOME MILESTONES IN ELECTROANALGESIA

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500 B.C.</td>
<td>Egyptian Fifth Dynasty, stone carvings show electric fish Malapterurus electricus used to treat painful conditions</td>
</tr>
<tr>
<td>400 B.C.</td>
<td>Hippocrates, used electric fish to treat headache and arthritis</td>
</tr>
<tr>
<td>1759</td>
<td>Dr John Wesley, in “Electricity made plain and useful by a lover of mankind and of common sense” described treatment of sciatica, headache, gout, kidney stones, etc.</td>
</tr>
<tr>
<td>1965</td>
<td>R Melzack &amp; P Wall, proposed the Gate Control Theory of Pain</td>
</tr>
<tr>
<td>1967</td>
<td>P Wall &amp; W Sweet, reported use of High-frequency (50-100Hz) percutaneous electrical nerve stimulation for relief of chronic neuropathic (neuropathic) pain</td>
</tr>
<tr>
<td>1967</td>
<td>CN Shealy et al., reported use of Dorsal Column Stimulation (DCS) of spinal cord</td>
</tr>
<tr>
<td>1969</td>
<td>DV Reynolds, discovered that stimulation of peri-aqueductal grey (PAG) in the midbrain produces surgical anaesthesia</td>
</tr>
<tr>
<td>1973-4</td>
<td>DM Long &amp; CN Shealy, reported results of transcutaneous electrical nerve stimulation (TENS)</td>
</tr>
<tr>
<td>1979</td>
<td>MBE Eriksson &amp; B Sjolund, reported increased analgesic efficacy of Acupuncture-like TENS compared with continuous TENS</td>
</tr>
</tbody>
</table>
generator. The controls are:

a. combined on-off switch / amplitude (intensity) control
b. frequency control: low (2-5Hz) to high (100-250Hz)
c. continuous / pulsed (burst) / ramped / random mode selector switch
d. width control: 220-500 microseconds
e. on multi-channel instruments an amplitude (intensity) control is provided for each channel.

Leads

A pair of insulated wires connect the stimulator to two electrodes. On one end of the lead is a miniature jack plug for connection to the stimulator. The other end contains two individual plugs which each connect to an electrode.

The leads are the weakest component in a TENS unit, especially at the junction between stimulator plug and cable and also between the cable and the plugs for the electrodes. Wherever possible the most supple leads should be used, because the wires inside the cable are less likely to fracture and also because supple leads are much more comfortable for the patient.

Electrodes

These are of two main types:

a. carbon-rubber (rubber impregnated with carbon to make it conduct an electric current)
b. self-adhesive

d. width control: 220-500 microseconds
e. on multi-channel instruments an amplitude (intensity) control is provided for each channel.

Use of the equipment

First, decide where to place the electrodes. Stimulating electrodes are used in pairs and should be positioned so that their edges are never less than 1cm apart, so as to avoid direct conduction (i.e. short circuiting between the electrodes). Electrodes should lie along the general direction of the nerves in the part of the body to be treated. For example: on the limbs the electrodes should be placed longitudinally (rather than transversely); on the trunk they should be placed along the course of the nerves or dermatomes (Figures 1a and 1b). Before applying electrodes always ensure that the skin is clean, dry and free from grease and powder.

Carbon-rubber electrodes are applied to the skin using conductive saline jelly and tape for fixation. The use of saline jelly is essential in order to achieve adequate electrical contact between the electrode and the skin. For this reason the jelly must be applied evenly over the whole of the surface of the electrode. Use only jelly designed for use with TENS; this normally contains 2% sodium chloride (and a bactericide); never use ECG jelly which often contains much higher concentrations of sodium chloride which will irritate the skin. The most satisfactory tape is Micropore because it is thin, flexible, easy to cut or tear into strips and does not usually irritate the skin. Alternatively, specially shaped pieces of tape designed to fit over an electrode can be obtained, but are more expensive.

Self-adhesive electrodes are supplied stuck to a piece of waxed paper. To use: peel the electrode off the wax backing and apply to the selected area, ensuring that the whole surface of the electrode is evenly in contact with the skin. To remove: pick up one corner of the electrode, peel it off the skin and immediately re-apply to the waxed paper. Finally, connect the electrodes to the stimulator by...
Table 2

<table>
<thead>
<tr>
<th>FORM</th>
<th>PULSE</th>
<th>EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Continuous (Conventional) high-frequency, low-intensity</td>
<td>Continuous, High 40-150 Hz</td>
<td>Non-painful paresthesia directed into area supplied by stimulated nerves.</td>
</tr>
<tr>
<td>2. Pulsed (burst) low frequency, low intensity</td>
<td>Bursts of 100 Hz at 1-2 Hz</td>
<td>As for 1 but felt in bursts.</td>
</tr>
<tr>
<td>3. Acupuncture-like (Acu-TENS) low-frequency, high-intensity</td>
<td>Bursts, Low, with Bursts of 10 Hz at 1-2 Hz</td>
<td>As for 1 but accompanied by non-painful twitching of muscles in those muscles stimulated.</td>
</tr>
</tbody>
</table>

Note:
1. On some stimulators, pulsed forms of TENS (forms 2 and 3) are available in a modulated or ramped form, so that the amplitudes of each set of shocks making up the pulse or burst are not equal, but form a rising staircase of increasing intensity. This pattern of pulsing produces a stroking sensation which is more comfortable for the patient.

2. On some stimulators a randomised, continuous output is available, the purpose of which is to reduce the development of tolerance to TENS, which may occur more readily with a regular pattern of stimulation due to habituation of the nervous system.

3. Stimulators are now available that produce complex wave forms designed to operate with a single pair of electrodes (Likon) or multiple electrodes activated randomly (Codetron) (2), and it is to be hoped that their role in TENS therapy, especially for palliative care, will soon become clear.

means of the leads, having first ensured that the stimulator is switched off. Switch on and adjust the stimulator according to the procedure set out below. It is important that electrodes of all types are removed from the skin at least every 24 hours.

Types of TENS
Select which one of the three types of TENS is to be used (Table 2):
1. Continuous (conventional) high frequency, low intensity
2. Pulsed (burst) low frequency, low intensity
3. Acupuncture-like (Acu-TENS) low frequency, high intensity.

The sensation produced by TENS should be “strong but comfortable”, not just tolerable, and the stimulus should be directed into the painful area. Neither continuous (conventional) nor pulsed (burst) TENS may be permitted to produce muscle twitching or spasm; by contrast, acupuncture-like TENS (Acu-TENS) is deliberately adjusted to a strength that evokes muscle twitching. To treat large areas of pain, dual (or multiple) pairs of electrodes may be needed. Use a double adaptor lead with a single channel stimulator; or a dual (or multiple) channel stimulator.

TENS trial
Initially a trial of TENS is necessary to ensure that the pain condition is not aggravated by TENS and to familiarise the patient with its use. It will also show whether the patient obtains pain relief within the trial period. However, if pain relief is not achieved within this time, it may still be achieved with longer periods of stimulation (hours). Hence the importance of ensuring that the patient continues to test TENS over a period of at least a fortnight. In the initial trial, it is essential that stimulation is carried out for a minimum of 1 hour. If this is not done, then a patient who does not respond to TENS in less than 1 hour may be deemed mistakenly to be non-responsive (4). The form of TENS that is optimum for a particular pain must be discovered by trial and error. Both continuous and pulsed TENS should be tried for every new pain treated.

Setting of controls
Continuous stimulation
1. Set all controls to zero (or minimum setting); and set mode switch to “Continuous” position.
2. Increase pulse Amplitude slowly to the maximum comfortable level i.e. strong but comfortable. This is usually a distinct end-point.
3. Increase pulse Frequency to the maximum comfortable level. This is also usually a distinct end-point.
4. Where available, increase pulse Width to a comfortable level.

Pulsed stimulation
1. Set all controls to zero (or minimum setting); and set mode switch to “Pulsed” Position. Then proceed with steps 2-4 as for Continuous stimulation (see above).

Acupuncture-like TENS
1. Proceed as for Pulsed TENS (see above) but in step 2 adjust pulse Amplitude so that muscles underlying the electrodes twitch visibly but not painfully.

Treatment plan
As for all other forms of treatment, it is important that the diagnosis should be established first. Even when a precise diagnosis cannot be made, it is essential to establish that TENS is an appropriate treatment for a particular pain i.e. that other, possibly more radical treatment for example surgery, is not required. Once the decision to use TENS has been made, the following procedure is adopted:
1. Trial session
2. Instruct patient in the use of equipment
3. Directions: Begin with a minimum of one hour three times a day. Adjust the controls according to need. Use TENS as long and as often as you like. You may get a bonus of a period of post-
stimulation pain relief, but don't be disappointed if relief is limited to the time that the TENS unit is actually in use.

4. Review at 1, 3, 6 and 12 months after the start of treatment and thereafter according to need.

**Complications of TENS**

**Skin irritation**
There is a 30% incidence of skin irritation under the electrodes, usually due to improper technique by the patient. The commonest cause is failure to clean carbon-rubber electrodes; these must always be washed with soap, rinsed and dried after use. Electrodes of all types must be removed from the skin at least once every 24 hours and should not be applied to the same piece of skin every day. Instead the electrodes should be moved to an adjacent area of fresh skin each day, thus ringing the changes.

**Allergic reaction**
Allergy to the electrodes, jelly or fixative, e.g. tape, gum, etc., is uncommon, but when this occurs the offending type of electrode, jelly or tape should be changed. Thus, carbon-rubber electrodes can be replaced by self-adhesive electrodes; TENS saline jelly can be replaced by K-Y jelly, which in theory is not conductive, but works in practice; and Micropore tape can be replaced by some other suitable tape.

**Electrical skin burns**
Excessive electrical current applied to denervated or poorly innervated areas of skin can result in burns.

### Table 3

**MAIN CHARACTERISTICS OF TENS STIMULATORS CURRENTLY AVAILABLE (8,9)**

<table>
<thead>
<tr>
<th>Country of design/manufacture:</th>
<th>Finland, Israel, Japan, U.K., U.S.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions:</td>
<td>6 x 4.9 x 1.78cm (smallest) to 12 x 8.5 x 3.6cm (largest)</td>
</tr>
<tr>
<td>Weight (including battery):</td>
<td>55-220g</td>
</tr>
<tr>
<td>Pulse width:</td>
<td>220 microsecond fixed or 10-500 microsecond adjustable</td>
</tr>
<tr>
<td>Pulse frequency:</td>
<td>1.5-100Hz adjustable; rarely fixed.</td>
</tr>
<tr>
<td>In some instruments “groups” or “bursts” of pulses are available at 2Hz</td>
<td></td>
</tr>
<tr>
<td>Channels:</td>
<td>1 or 2</td>
</tr>
<tr>
<td>Battery type (with or without optional rechargeable kit):</td>
<td>PP3, 2 x AA or special</td>
</tr>
<tr>
<td>Battery life:</td>
<td>40-120 hours (occasionally 4-16 hours)</td>
</tr>
<tr>
<td>Guarantee:</td>
<td>6 months to 2 years</td>
</tr>
<tr>
<td>Cost:</td>
<td>£50-£250 + VAT.</td>
</tr>
</tbody>
</table>

N.B. In the UK, stimulators were eligible for relief from VAT under Group 14 of Schedule 5 to the Value Added Tax Act 1983. Subsequently this arrangement was withdrawn, but recently it has been reinstated for certain stimulators designed specifically for chronic pain.

### Table 4

**MODIFICATIONS TO THE BASIC TENS STIMULATOR**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acupuncture-like TENS</td>
<td>High-intensity/low frequency TENS</td>
<td>Increases efficacy; some patients who fail to respond to continuous stimulation will respond to this form.</td>
</tr>
<tr>
<td>Codetron stimulator (2)</td>
<td>Uses multiple electrodes which are excited randomly</td>
<td>Claimed to increase efficacy.</td>
</tr>
<tr>
<td>Likon stimulator</td>
<td>Shocks delivered on a complex high frequency carrier wave</td>
<td>Claimed to increase efficacy by achieving deeper penetration of the tissues by electrical stimulation.</td>
</tr>
<tr>
<td>Hi-wave stimulator</td>
<td>Biphasic wave with exponential decay</td>
<td>Claimed to increase efficacy and to be a more comfortable form of electrical stimulation.</td>
</tr>
<tr>
<td>Micro-current TENS</td>
<td>Very low current (µA) delivered at very high frequency</td>
<td>No sensation of stimulation produced (mechanism of action). Claimed to be more effective than ordinary TENS.</td>
</tr>
<tr>
<td>Transcutaneous Spinal Electroanalgesia (TSE)</td>
<td>Very brief pulses (4µs or less) at high voltage (circa 400V)</td>
<td>Stimulation of skin via electrodes overlying the spinal cord. No sensation of stimulation.</td>
</tr>
</tbody>
</table>

Before using TENS always check that there is normal sensation in the skin to which the electrodes are to be applied.

**Equipment failure**

Apparent failure of previously successful treatment may be due to failure of leads, stimulator, battery or charger (where rechargeable batteries are used). The leads are the most vulnerable part of the system and the wires may fracture at their connections to the plugs. Also check that the plugs connected to the electrodes are not dirty, corroded or heavily oxidised. Always check the battery and replace with a new one if in doubt.

**Tolerance**

Tolerance to TENS stimulation may occur, with a reduction in analgesic effect. First check that the stimulator is working normally and that it is being used correctly. Apparent tolerance may be due to worsening of the pain problem; nevertheless in about 30% of patients tolerance develops slowly with the passage of time. When this occurs, consider changing the pulse pattern i.e. from continuous to pulsed or to random (if available), or temporarily withdrawing TENS to permit reversal of tolerance.

**Contraindications**

TENS should not be used on a patient with a cardiac pacemaker, nor on a non-compliant patient such as the mental handicapped, senile or with a low IQ. Stimulation over the anterior part of the neck (carotid sinus, laryngeal muscles) should be avoided, as should stimulation over the pregnant uterus, except during TENS for pain relief in labour.
Figure 2. Neuronal circuits involved in TENS and acupuncture analgesia (10).

Abbreviations
Aβ, C and Aδ represent the posterior root ganglion cells of A beta, C and A delta fibres, respectively; Arcuate n. = Arcuate nucleus; DCS = dorsal column stimulation; Enk = enkephalinergic neurone; GABA = gamma-aminobutyric acid; 5-HT = 5-hydroxytryptamine; NAd = noradrenaline; nRG = cell in nucleus Raphe Gigantocellularis; nRM = cell in the nucleus Raphe Magnus; PAG = periaqueductal grey; SP = Substance P; OP = opioid peptides; SG = cell in the Substantia gelatinosa (lamina II); T = transmission cell; VIP = vasoactive intestinal polypeptide; W = Waldeyer cell.
Electrodes
There are two main types available: reusable and disposable. Reusable electrodes are conductive rubber pads for use with electrode jelly and tape. They are available in a wide range of shapes and sizes, but those commonly used are rectangular: 40 x 40mm (small), 93 x 42mm (large), 210 x 40mm (post-operative); or circular (for the face): 28 or 50mm diameter.

Self-adhesive, conductive polymer pads, which do not require jelly or tape, are available in the same range of sizes as the rubber pads. The anticipated life of these electrodes varies with manufacturers, but is usually about 10-14 days. However, in practice and with care, the useful life can be substantially longer.

Disposable electrodes are self-adhesive, conductive polymer pads, again available in the same range of sizes but with an anticipated life of only 2-4 days. It should be noted that conductive rubber pads can be converted into self-adhesive electrodes by the use of Karaya pads (double sided sticky) which eliminates the need for jelly and tape, and makes self-administration of TENS more practicable, especially for the elderly living alone. Some disposable electrodes are now available using pre-gelled silver/silver chloride construction in order to avoid polarisation. However, with stimulators of modern design this is not usually a problem. Other uncommon types of electrodes are available such as cotton pads and stainless steel, but these are rarely used.

Other types of TENS
Since TENS was first introduced, sustained efforts have been made to improve every aspect of this method of electroanalgesia, especially its efficacy. Some of these developments are listed in Table 4.

Mechanism of action
The precise way in which TENS and acupuncture produce analgesia is still not completely clear. However on the basis of a considerable body of evidence now available, it appears that peripheral and central neuroanatomical and neuropharmacological mechanisms are involved. Figure 2 shows the neuronal circuits thought to be involved in TENS and acupuncture analgesia, and also indicates some of the neuropharmacological agents concerned. The afferent pathways transmitting nociceptive information from a painful and inflamed area to the higher centres via the dorsal horn, ascending tracts and thalamus are shown. Also shown are the connections to the descending inhibitory pathways which descend in the dorsolateral funiculus. The connections to the hypothalamus are also indicated.

Acknowledgements
I should like to thank Oxford University Press, the editors of the Oxford Textbook of Palliative Medicine and Dr Jacqueline Filshie, the co-author of our chapter TENS and Acupuncture, for permission to use figures, tables and text from this book (10).

Professor John W Thompson PhD FRCP
Honorary Consultant in Medical Studies and
Honorary Physician
St Oswald’s Hospice, Regent’s Avenue
Cosforth, Newcastle upon Tyne NE3 1EE

References and source material

Do you want to start using acupuncture in your practice or hospital clinic.

Come on a BMAS course to learn the basics of medical acupuncture. Don't be put off by unfamiliar Chinese mediadeval theories. The course explains acupuncture in a western medical setting and covers an up to date view of the neurophysiology and anatomy of stimulation induced analgesia together with good detail of trigger point theory. There is plenty of needle practice and by the end of the course any doctor should feel confident to treat simple problems with acupuncture.

For more advanced theory and practice, there are a variety of further courses and regular meetings for members of the British Medical Acupuncture Society - not to mention free copies of this most excellent journal!
Transcutaneous electrical nerve stimulation for the relief of pain

John W Thompson

doi: 10.1136/aim.13.1.35

Updated information and services can be found at:
http://aim.bmj.com/content/13/1/35

**Email alerting service**

Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

**Notes**

To request permissions go to:
http://www.bmj.com/company/products-services/rights-and-licensing/

To order reprints go to:
http://journals.bmj.com/content/subscribers

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/