

Overview

Transcutaneous Spinal Electroanalgesia (TSE) is an electrical pain relief modality first discovered in 1991. Since its introduction, over 100 UK pain clinics and more than 20,000 patients have used TSE devices in the home with no significant side effect or interaction with medication reported.

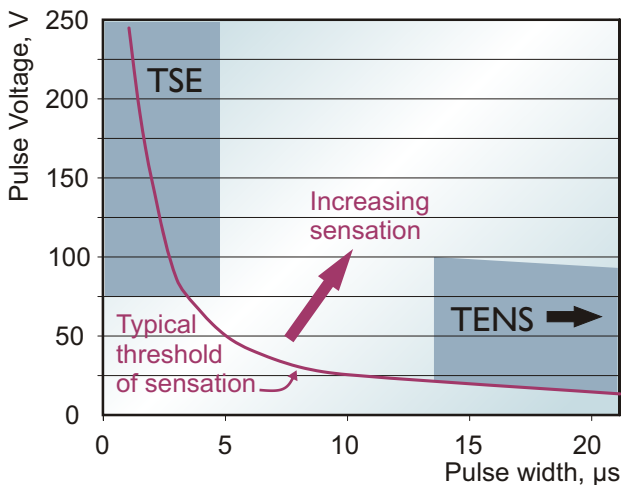
TSE employs a signal that is so brief in duration (four microseconds or less) that it tends not to cause action potentials in peripheral nerves until high voltages are reached.

Each TSE signal is a square wave with such a fast rise and fall time that most of the energy is expressed in the radio frequency range. The resistance to electrical signals in human tissue falls by a factor of four as frequency is increased from typical TENS to TSE frequencies. These factors permit deep penetration of tissues by TSE signals without causing uncomfortable sensations.

The penetrating quality of the waveform allows surface electrodes to be used, even though a beneficial effect is desired in tissues lying at some depth, for example the central nervous system.

The earliest findings were made with the electrodes placed over the spinal cord – hence the term Transcutaneous Spinal Electroanalgesia, or TSE.

Acticare is a British designed and manufactured product that synthesizes TSE waveforms, but also produces a wide range of standard and high frequency TENS, radio frequency and Interferential waveforms.



TSE pulses are higher in intensity than standard TENS but because of their very short duration they induce only slight tingling sensations even at high current levels. Therefore, the therapy tends to be well tolerated.



Acticare TSE may be employed peripherally as a high power, high frequency TENS machine, but the TSE modes are particularly convenient because they work on the central nervous system; only two electrode placements are needed to cover pains anywhere in the body.



The Acticare device family includes two variants: one providing TSE and TENS and another that adds Interferential therapy and square-wave modes from 1 Hz to 500 kHz. Despite its small size, the device delivers ten times the power of a typical handheld TENS machine.

Introduction and History

Transcutaneous Electrical Nerve Stimulation (TENS) is a popular form of electroanalgesia and can be used safely in the patient's home for the relief of chronic pains. It is also effective against postoperative pain at high levels of stimulation (Bjordal *et al* 2003).

However, there are a few limitations to its use: its effectiveness may reduce over a period of time and the period of post-stimulation relief tends to be brief. Furthermore, with TENS it is often difficult to know where to place the electrodes and TENS does not stimulate enough A β fibres in peripheral nerves to reduce pain in large tender regions.

In order to overcome these shortcomings in TENS, Shealy in 1971 implanted wires in the spinal canal to induce analgesia. This technique is called Spinal Cord Stimulation (SCS). Spinal Cord Stimulation can be very effective against longstanding pain, but has the disadvantage that surgery is required to implant the electrodes.

In 1991, inspired by the success of TENS and SCS, Drs Alex Macdonald and Tim Coates discovered Transcutaneous Spinal Electroanalgesia (TSE) and were granted patents on the technology in 1995 and 1997.

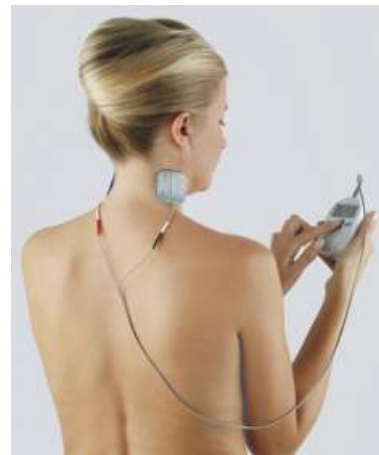
TSE pulses are very short in comparison to TENS and SCS: typically four millionths of a second (4 μ s) in length as compared with typically 50 μ s or more in the case of TENS and SCS. Brief though they may be, TSE signals employ a relatively high voltage and current. This allows the pulses to pass through the skin and tissues to the spinal cord. These pulses cause little sensation, so the process is well tolerated.

TSE has been practised as a form of electrical pain relief since its discovery in 1991. No serious side effect or interaction with medication has been reported in over 14,000 (March 2006 figures) users in the United Kingdom. Wherever the painful region may be, two surface electrodes are placed over the spinal cord (see figs 1 and 2).

Fig 1 Spinous processes of T1 and T12



Fig 2 Transverse processes of C3/4



With TSE, two primary electrode placements are used: overlying the spinous processes of T1 and T12 for painful regions lying below the shoulders (Fig 1) and across the neck overlying the transverse processes of C3/4 for pains in the upper thorax, neck, upper limbs and head (Fig 2).

Fig 3 The new Acticare TSE device.

Every device is supplied with a charging cradle and rechargeable batteries to minimise the cost of ownership and a high quality carry bag.



Acticare Electrotherapy Unit

TSE devices were first introduced in 1995 and have been manufactured by a number of companies under licence. In 2004, Bioinduction Ltd took assignment of the patents and a completely new and more powerful TSE device was developed. This is called Acticare.

Two versions are available approved for sale in Europe, Canada and Australia:

- Acticare TSE, intended for home users, providing TSE, TENS and neuromuscular stimulation capability;
- Acticare IC, intended for use by physiotherapists and other practitioners, which adds Interferential stimulation and pulsed radio frequency modes.

In addition, two new versions were introduced in 2010 for sale in USA and Canada:

- Acticare HFT, approved by FDA for symptomatic treatment of chronic pain, post operative and post surgical pain, intended for home users on the order of a physician, providing high frequency TENS and neuromuscular stimulation capability;
- Acticare HFI, intended for use by physiotherapists and other practitioners, which adds Interferential stimulation to Acticare HFT.

All units provide multiple treatment modalities and a fully programmable advanced user mode. Acticare is unique in that it delivers the power output of a professional desktop electrotherapy machine in a battery powered device that you can carry in your pocket. This is achieved using a revolutionary method of digital waveform synthesis that is far more efficient than traditional designs.

Standard electrotherapy modalities incorporated in Acticare TSE and IC are:

- Transcutaneous Spinal Electroanalgesia (TSE).
- Transcutaneous Electrical Nerve Stimulation.
- High Frequency TENS.
- Interferential Current (IC model only).
- Transcutaneous Pulsed radio frequency (PRF) (IC model only).

In addition, the waveform is quickly programmed via Acticare's menu system to provide additional TENS frequencies and the following modalities:

- Acupuncture-like TENS (AL-TENS) down to 1Hz.
- Neuromuscular stimulation (NMES).

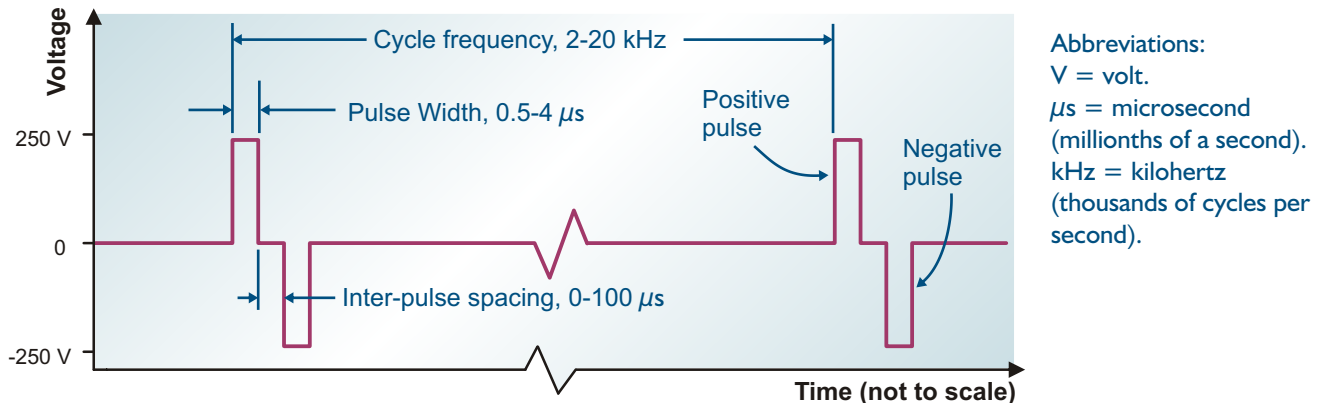
Table 1 Feature Comparison of Acticare TSE and Acticare IC models

Model	Acticare TSE	Acticare IC
TSE modes	3 (500 Hz, 2500 Hz, 10 kHz)	3
TENS modes	6	6
High Frequency TENS modes	2 (500 Hz)	2 (500 Hz)
Acupuncture-like TENS (AL-TENS) down to 1Hz	Yes – user programmable waveform	Yes – user programmable waveform
Neuromuscular stimulation (NMES) Modes	Yes – user programmable waveform	Yes – user programmable waveform
Transcutaneous Pulsed Radio-frequency (PRF) modes	No	Yes - 2 preset modes plus user programmable mode
Interferential Current (I/F) modes	No	8 preset modes plus user programmable mode
Advanced modes	Frequency: 1 Hz to 20 kHz Pulse width: 0.5 μ s to 200 μ s Voltage: 0 - 250 V	Frequency: 1 Hz to 500 kHz Pulse width: 0.5 μ s to 200 μ s Voltage: 0 - 250 V
Outputs	One	Two coupled
Treatment timer	10 mins to 3 hours	10 mins to 3 hours (TSE & TENS) 1 to 30 mins (Interferential modes)
Display	LCD	LCD
Real time clock	Yes	Yes
Pain Diary	Yes	Yes (TSE & TENS modes only)

Abbreviations: V = volt. μ s = microsecond (millionths of a second). kHz = kilohertz (thousands of cycles per second).

Typical parameters of a TSE waveform.

Fig 4 Typical single cycle bi-phasic TSE waveform, time axis not shown to scale.



TSE pulses are of square waveform and characterised by very high rates of change of voltage which in turn induce a rapidly changing oscillating electric field in the tissues. The pulses may be delivered as single cycles, separated by quiet periods and repeated at regular intervals (typically 2,000 to 20,000 times per second) as illustrated above in fig 4. Alternatively, the pulses may be delivered in short bursts at rates of up to 500 kHz as illustrated in fig 5.

The pulses may be monophasic or biphasic; the biphasic form is preferred as zero net current flow reduces the possibility of electrolytic reactions at the site of the electrodes due to ionic transport. Typically a biphasic square wave of duration four microseconds or less is employed.

Four microsecond TSE pulses are too brief to produce action potentials in peripheral nerves at voltages below 150 V (peak-to-peak). With shorter pulses, of the order of 0.5 μ s, the voltage may be increased to 500 V or more before the threshold of sensation is reached.

Interferential stimulators employ high frequency carrier signals so that they can penetrate deeper into the body. The same is true of TSE, the short duration and high frequency of the waveform allows TSE to penetrate deep tissues more effectively than TENS. This is because at frequencies employed by TSE human tissue

impedance is about 150 ohms, or just one third of the level seen by typical TENS machines.

Acticare TSE has three different standard TSE therapy modes (see Table 2). First time users should use TSE 1 therapy mode for pain relief. Acticare TSE is factory preset to TSE 1 mode so there is no reason to change these settings on first use.

In addition, Acticare TSE incorporates an advanced mode that allows experienced users to vary the pulse width, interpulse spacing and repetition frequency independently.

The professional device, Acticare IC incorporates the three TSE modes from Acticare TSE, but adds burst modes as illustrated below, at 250 kHz and 500 kHz. These are analogous to pulsed RF used in percutaneous RF treatments.

Fig 5 Burst mode bi-phasic TSE waveform.

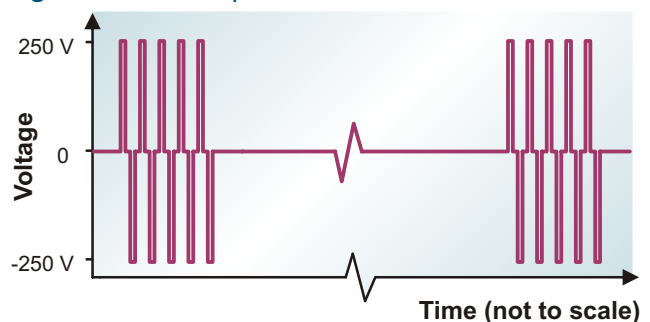


Table 2 Acticare TSE has three standard TSE preset modes

Therapy mode	Waveform	Recommended For
TSE 1	1.5 μ s biphasic pulse repeated at 2,500 Hz.	Default mode of operation for chronic pain and first time users. Causes a mild tingling sensation at high levels of stimulation.
TSE 2	0.5 μ s biphasic pulse repeated at 10,000 Hz.	Suitable for acute-on-chronic conditions or those where TSE 1 has not helped. No sensation in most users, except a feeling of warmth at high intensities, well tolerated especially when used across the neck where tingling caused by TSE 1 might be distracting or uncomfortable.
TSE 3	4 μ s biphasic pulse repeated at 250 Hz.	Improvement in mood and reduction of fatigue as demonstrated in a clinical study by Towell et al 1997. Marked tingling sensation at high intensities. Lower power output than TSE1 and 2. Also useful applied peripherally as a high power TENS style therapy.

Clinical Studies on TSE

Studies in man have shown pain relief by TSE for various conditions is affected by frequency and power delivered.

First generation battery operated TSE devices were lower powered and less effective than the latest Acticare device, which has the power output of a desktop TSE unit from a battery supply.

At first in 1991, TSE was employed at a frequency of 100 Hz, similar to many TENS machines. But since then, higher frequencies have been employed in a series of upward steps.

In a pilot study of chronic unilateral tenderness, TSE at 600 Hz produced a significant reduction in the ratio of thresholds of mechanical pressure and cutaneous sensitivity of the affected side as compared with the thresholds of the control side ($p < 0.001$).

In another pilot study of 100 consecutive patients, approximately two thirds reported at least 60% pain relief (Macdonald and Coates 1995). As treatments were repeated, those that received benefit fell into two groups:

- Approximately half reported an accumulative effect from TSE. They required a few weekly treatments to produce continuous relief.
- The remainder reported a consistent duration of short-term relief lasting from several hours to a day or more: these patients needed to continue TSE on a regular basis at home.

None reported a reduction in effectiveness with repeated usage.

A formal, randomised, double blind, crossover clinical trial (n=8) performed by Macdonald and Coates 1995 comparing TSE (at a frequency of 10 kHz) with a control form of stimulation (TENS) for the relief of chronic pain, showed the analgesic effects of TSE to be significantly superior ($p < 0.005$).

Treatment time for chronic pain is on average thirty minutes. The duration of relief of chronic pain following the first treatment is on average eight hours. This phenomenon is particularly useful in the management of conditions such as migraine, non-specific back pain, post-trauma or post-operative pains where no inflammation persists.

Effect of increasing frequency and power output

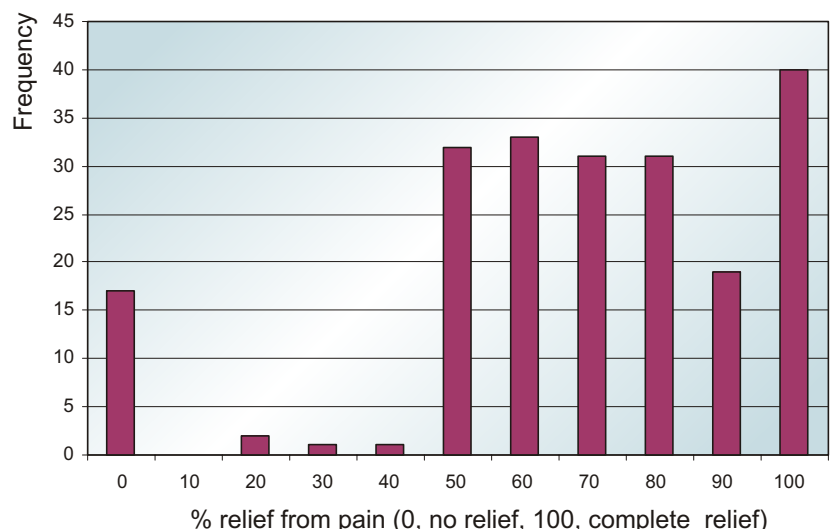
When the cycle frequency of TSE is increased to 10kHz or more, not only chronic pain can be treated but also acute and acute-on-chronic pains tend to be reduced - for a few hours.

When TSE was performed at high power and a cycle frequency of 20 kHz, Macdonald 2000, discovered in an open pilot study on 207 patients that within an average treatment duration of 15 minutes pains of

acute conditions were reduced, e.g. inflammatory arthritic pain (see figure 6).

Important note: TSE should only be used to treat acute pain under medical supervision where a diagnosis has been made by a health care professional. For this reason, the standard settings of the Acticare TSE device are those applicable only to chronic pains.

Fig 6 Frequency distribution of relief (0, no relief; 100, complete relief) of all types of acute and acute-on-chronic pain conditions (n=207) treated by 20kHz TSE.



Effects of TSE Usage on General Practitioner Consultation Rates

An investigation was carried out in 1999 into the effects of TSE usage on General Practitioner consultation rates. This was performed along the lines suggested by the Audit Commission's earlier study confirming the cost-effectiveness of Pain Relief Clinics ("No Feeling, No Pain!", Audit Commission, London, 1997 quoted in "Evidence-Based Resource For Pain Relief", McQuay H & Moore A, Oxford University Press, 1998).

Sixty patients who were using TSE in their homes were selected at random and a study made of their GP records. Consultation rates of the patients in the six months prior to acquiring a TSE device were compared with those in the first six months of TSE usage.

This study showed an average consultation rate before acquiring the TSE device of 2.96 visits per patient compared with 1.84 visits during use. This represents a reduction in the consultation rate of 38.7%.

The Audit Commission paper demonstrated a similar reduction (40%) in GP consultation rates for patients attending Pain Relief Clinics. This study seems to suggest that TSE is not only a cost-effective form of treatment in primary care but also can cause a significant reduction in General Practitioner workload.

Effects on mood

A controlled study of TSE at 625 Hz conducted in the University of Westminster (Towell, Williams and Boyd, 1997) revealed significant changes in mood in healthy subjects, but only when electrodes were placed over the spinal cord.

The study investigated the effects of non-invasive high frequency stimulation over the spine on mechanical pain tolerance and subjective mood, the researchers having previously noted a change in mood in patients being treated with TSE.

Sixty healthy subjects were divided equally into three groups receiving either high intensity (250 V), low intensity (3.4 V) or sham electrical stimulation, directly over the spinal cord for 30 minutes. A Nowlis Mood Adjective Checklist and a mechanical pain pressure tolerance of the finger nail were used before and after treatment.

Following high intensity stimulation, TSE subjects felt "significantly more elated, leisurely and less tense".

Table 3. Summary of Results - High frequency non-invasive stimulation over the spine

1. The table shows mean change values of emotions following TSE.
2. Positive values represent an emotion being felt more strongly.
3. Following high intensity TSE, subjects felt significantly more elated (***) ($p < 0.001$), leisurely (*) ($p < 0.05$) and less tense (**) ($p < 0.01$)

Stimulus Intensity	Response		
	Tense	Elated	Leisurely
High	-0.75**	0.6***	0.75*
Low	-0.3	0.35	0.25
Sham	-0.3	0	0.2

Chronic musculoskeletal pain and 10kHz TSE

The effect of TSE on chronic musculoskeletal pain was investigated by Macdonald and Coates 1995 in Bristol. This was a randomised, double blind, cross over study, designed to compare the pain-relieving effects of a single 20 minute treatment of TSE with a control treatment provided by TENS in consecutive patients suffering chronic musculoskeletal pain.

Self-adhesive electrodes were placed on the skin in the mid-line of the back over spinous processes, the anode at the level of T1 and the cathode at the level of T12. A TENS device (pulse width 200 µs; fast rise time and a fall time decaying exponentially; uninterrupted frequency 100 Hz) and a TSE device (pulse width 1.5 µs; square waveform; frequency 10 kHz) were linked to the patient by means of an enclosed junction box. Each junction box was coded so that on one occasion the same patient received TSE and on the other occasion, usually a week later, TENS, in random order. This was not a comparison of the effects of TSE with the usual practice of TENS. TENS is normally applied to the same region as the pain, and tends to be ineffective when applied to an unrelated nerve trunk (Woolf 1989). Sensations derived from TENS were employed as a control, so the patient was aware of electrical stimulation on both occasions.

As pain is so difficult to quantify, the effects of each treatment on several measures of efficacy were employed. The percentage reduction of five measures of efficacy were recorded by means of the following types of instrument: pain scores; physical sign scores; surface area of referred pain drawn by the patient on a body outline; surface area of tender region found by the practitioner. The percentage increase in pain pressure threshold in the most tender region was also recorded.

The means of the five measures of pain control efficacy (and all five combined) of the two treatments are compared in Table 4 below. The average percentage changes of all five measures of success produced by TSE were significantly greater than those produced by the control TENS treatment, and in every case the differences between the two were significant when tested by Wilcoxon rank sum tests. A comparison of all measures of efficacy combined between TSE and control treatments shows that TSE is significantly more effective than the control ($p < 0.005$).

Table 4 Comparison of the mean % changes in five measures of efficacy of 10 kHz TSE and TENS: a clinical trial, n8. Macdonald and Coates (1995)

Treatment	Average McGill Quest. pain score Reduction %	Average Reduction in physical sign scores %	Average reduction in referred area of pain %	Average reduction in area of tender region %	Average increase in pain pressure threshold %	Combined average % change
TSE	70	51	74	94	106	79
TENS	27	3	43	-11	-1	12
Significance of difference*	$p < 0.005$	$p < 0.01$	$p < 0.01$	$p < 0.005$	$p < 0.005$	$p < 0.005$

* Significance assessed by Wilcoxon rank sum test

Outcome Study of TSE in the home

Acticare TSE is often used by patients for self-treatment at home, without the direct guidance of a physician. An in house study of outcomes for home users was performed using a formal pain scoring system, sent to patients on receipt of the device and one month thereafter. A total of 476 responses was recorded at February 2010.

The study looked at changes in pain scores over the first month of use of the device. The questionnaire used was the Brief Pain Inventory (Short Form) – a standard, validated pain questionnaire that is widely employed in pain studies. The form asks people to rate

their pain in four categories (worst in last 24 hours, least in last 24 hours, average and right now) as a Visual Analogue Scale (VAS) pain score.

Overall, the reduction in VAS pain scores was 27% across the group, but with a 45% reduction in the sub-group that used the default TSE mode, TSE1 with electrodes placed in the standard T1 and T10 locations recommended for TSE. Median duration of pain was eight years and average age 67 years (n476). The data was analyzed using the Wilcoxon matched pairs method and is extremely significant ($p < 0.0001$).

Indications

Conditions which respond well to TSE are chronic or chronically recurring pains, for example post-operative pains, migraine, cervical spondylosis, chest wall pains, abdominal pains (such as menstrual pain and chronic pancreatitis), non-specific lumbar pains, sciatica and limb pains.

In addition, TSE can relieve neurogenic pains such as post herpetic neuralgia. The fact that both neurogenic

and somatic pains tends to be relieved is an indication for TSE in palliative care. However its effectiveness is reduced when there is pain on movement as occurs in active inflammatory conditions.

Thus an early osteoarthritic pain, where pain is not always produced by weight-bearing, usually responds better than a more severe condition requiring surgery.

Contraindications

In common with other electrotherapy equipment of similar output levels, there are a number of contraindications to using the device. These include: cardiac pacemakers; epilepsy and transthoracic stimulation (across the chest). Also, caution is required if there are any metallic implants near the electrode sites.

TSE is not recommended during pregnancy since foetal maturation responses are not known. Full information is given in the user manuals which may be downloaded from the product section on the Acticare website: <http://www.acticare.com>.

Monitoring effectiveness of TSE

Acticare incorporates a unique built-in pain diary. When enabled this prompts users to rate their pain on the LCD screen on a Visual Analogue Scale (VAS) before and after treatment. The diary records not only the patient's pain ratings, but also the time, date and intensity settings with which the device was used. On return to the clinic, the physician can download this data to a PC for analysis.

Fig 7 Pain Diary Entry Screen on Acticare TSE



Comparison with TENS devices and other electrotherapy devices

TSE pulses are of higher voltage, shorter duration and higher power than TENS.

The Acticare TSE device looks very similar in size and shape to a TENS device, but its size is deceptive: under typical treatment conditions it delivers between five and ten times the output power.

The graphs below show a good quality handheld TENS machine at maximum output connected to a standard 500 Ω load, compared to the Acticare TSE device under typical operating conditions of 80% of maximum output.

The vertical (voltage) scale in Fig 10 is five times that of Fig 9, and the horizontal (time) scale in Fig 10 is 200 times faster than that of Fig 9.

When the two signals are compared: this particular TENS pulse is of 250 μs duration, and the positive going portion is 50 V (peak to baseline) - its repetition rate is 100 Hz. The TSE signal is of much shorter

duration, 2 μs in this example, and the positive and negative going portions are of higher voltage (200 V) with a repetition rate 100 times faster at 10,000 Hz. The pulse itself is similar to a sine wave with a frequency of about 250 kHz, well into the radio frequency range. Because of the shorter pulse width, there is no fall-off in voltage during the pulse, which results in a greater transfer of charge into the tissues than can be obtained by TENS.

Under these conditions, the therapeutic current delivered by the TSE device is 80 mA (milliamperes) rms compared to 14 mA in the TENS device. Because the voltage is also higher, the power delivered is more than ten times greater in the TSE device.

The power output of the TSE device is in fact similar to the power output of one channel of a mains powered desktop interferential electrotherapy machine. A comparison of the power output of Acticare TSE compared to a good quality TENS machine and other devices is given in the table below.

Fig 9 TENS pulse Boots TENS machine model 2BT (vertical axis 10 V per division, horizontal 100 μs per division)

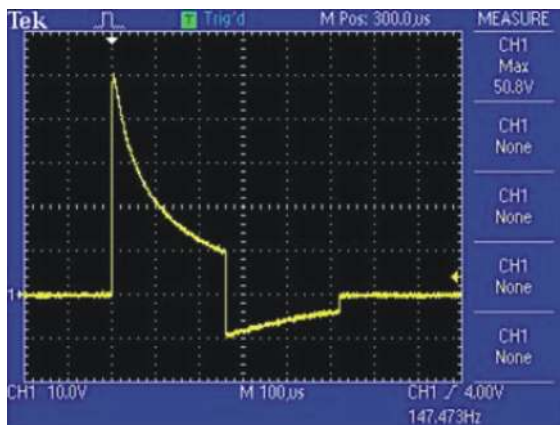


Fig 10 Typical TSE pulse - Acticare model TSE (vertical axis 50 V per division, horizontal 0.5 μs per division)

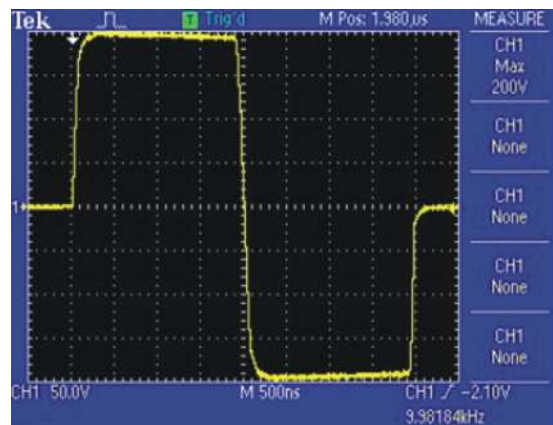


Table 5. Comparison of output characteristics and power capability of Acticare TSE and other electrotherapy devices

Device	Manufacturer	Description	Mode of operation	Pulse width (μs)	Peak voltage (Volts)	Frequency (Hz)	Power output (mW)	Relative Power Output
2BT	Boots	Premium quality home use TENS machine	Max output	250 μs	50V	150	179	1.0
Acticare TSE	Bioinduction	TSE device	Max output	2.0 μs	200V	10,000	3,200	17.9
Interferential 950	Electro-Medical Supplies	Desktop Interferential Machine	Max output	N/A (sine wave)	130V	4,000	4,141	23.1

Abbreviations: V = volt; mW = milliwatt (thousandths of a Watt); μs = microsecond; Hz = hertz (cycles per second).

Peripheral nerve sensation with TSE

When nerves are stimulated by a TENS pulse, it is generally accepted that sensation increases as stimulation current is increased. However, this assumption does not hold true for the high frequency and short pulse waveforms of TSE.

Figure 11 reveals the effects of the minimum amplitudes required to produce sensation from 50 mm square surface electrodes placed on the forearm at a variety of pulse durations from 0.5 to 20 μ s. At each given pulse duration, the effects of four different cycle frequencies (ranging from 100 Hz to 5 kHz) were compared.

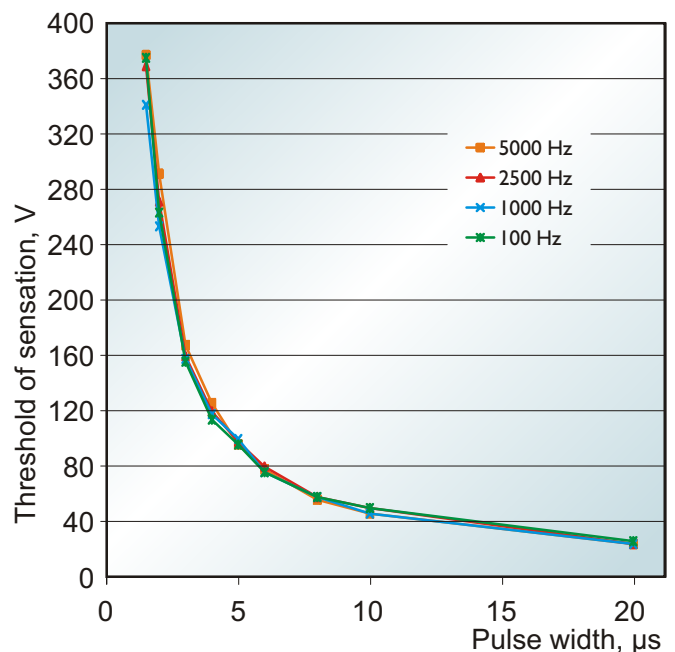
It can be seen that at each pulse width in this range of frequencies, the threshold of sensation does not vary even at stimulation rates well above the accepted physiological limits (800-1200 Hz). Thus at a given pulse width, the number of cycles and hence the average current can be controlled without affecting the threshold of sensation.

For example, with a pulse of 2 μ s duration, at the threshold of sensation the experimentally measured mean modulus current at 100 Hz was 0.27 mA, whereas at 5,000 Hz it was 13.5 mA, 50 times greater. With a typical TENS pulse of 50 μ s, the former level of current would exceed the pain threshold and the latter would be intolerable.

Therefore, with TSE, the ability to deliver high average currents at high voltages independently of sensation levels allows those modes of action based on electric field effects to be maximized and penetration of large volumes of deep tissues to be achieved.

Even though TSE need not generate any sensation, even at high levels of current, a gentle tingling sensation is often reassuring to the patient and this may also play a role in the expression of neurotransmitters. For this reason, two of the standard modes implemented on the Acticare TSE device (TSE modes 1 and 3) are configured so that they do produce some sensation at maximum output.

Fig 11 Relationship between threshold of sensation and voltage at different pulse widths and four cycle frequencies. (Biphasic square wave - Voltage is peak-to-peak value).



Safety

Since 1991, TSE has been used in over 100 NHS pain clinics and by over 14,000 patients without reports of serious side effects or interactions with medication.

The Acticare TSE device is designed in accordance with the IEC medical devices standard 60601-2-10 "Particular requirements for the safety of nerve and muscle stimulators". The circuit design is intrinsically safe so that it cannot generate a sustained harmful average current, nor deliver a pulse charge of more than the value which is safe through the chest, even in the event of software or component failure.

A feature of TSE treatment is that the patient becomes relaxed which is sometimes associated with drowsiness or a light-headed feeling. Patients so affected are advised not to drive or operate machinery.

In rare cases and in common with other types of electrotherapy, the patient may experience reddening at the site of the electrodes; this may be alleviated using an electrode gel designed for sensitive skin.

Mechanisms of Action and the link with Pulsed Radio Frequency

The mechanisms of TSE are theoretical but are believed to be a combination of the modes of action of pre-existing forms of electrically induced pain relief such as TENS and SCS, plus additional effects caused by the high rates of change of the applied electric field.

TENS effects such as the “pain gate” theory and expression of neurotransmitters such as GABA (γ -aminobutyric acid) are well known. They apply to TSE waveforms which have a pulse width and voltage sufficient to stimulate peripheral nerves.

TSE pulses of less than one microsecond will not stimulate peripheral nerves even if the peak-to-peak voltage is increased to 500 V. Employing such a brief pulse width allows radio-frequency waveforms at higher voltages to be applied without discomfort. The Acticare device can apply an electrical signal typically of frequency 500 kHz and 400 V peak-to-peak.

Effects on receptors and other cellular structures that result from the application of radio-frequency electric fields have been studied only in recent years and the mechanisms relating to pain relief have yet to be fully understood.

Because of its square waveform, TSE therapy produces oscillating electric fields in the tissues covering a wide spectrum of frequencies. Both single cycle (fig 4, page 4) and burst mode TSE (fig 5, page 4) are radio-frequency signals. Fourier analysis shows that single cycle TSE has a wide spread of energy across the frequency spectrum peaking at typically 400 kHz, whereas burst TSE has a marked peak at 500 kHz (see fig 12). Where these energy peaks occur depends on the pulse width employed rather than the repetition or burst frequency. TSE may therefore be considered a form of transcutaneously applied pulsed radio frequency.

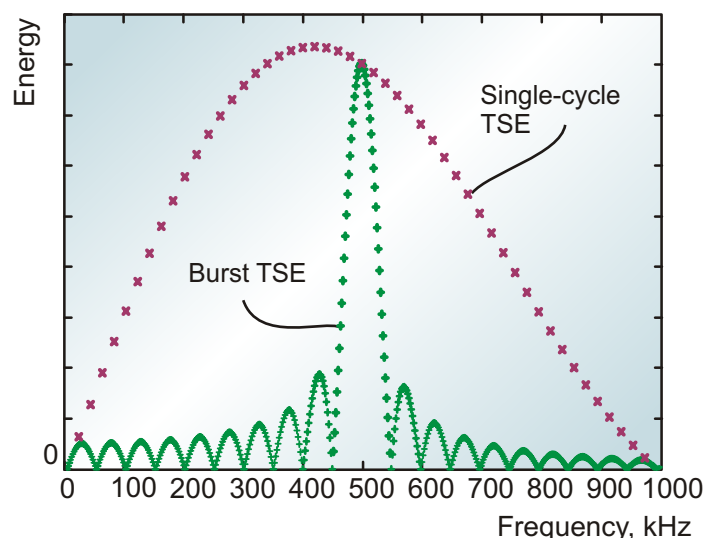
When thermal levels of radio frequency are applied directly to peripheral nerve tissues such as dorsal root ganglia or spinal nerves innervating inflamed regions, neuroablation (destruction of neuronal tissues) occurs in a pear shaped region around the needle tip. This has been widely used for the treatment of intractable chronic pain. In recent years however, pulsed radio frequency at non-thermal levels has also been shown to be effective (Sluijter et al 1998). Balogh (2004) observed a duration of effect up to four weeks after treatment with transcutaneous pulsed radio-frequency. This is consistent with studies of patients using high frequency TSE, where 50% report that in the long term they can maintain their pain relief with treatments every few days.

In essence, high frequency TSE and pulsed radio frequency are very similar. In common with Pulsed RF, high-frequency short-pulse TSE may be particularly suitable for treatment of neurogenic pains.

Direct coupling between applied field and cell structures has been observed by such researchers as Liu *et al* 1990, who identified direct effects of oscillating electric fields on the activation of Na^+ and K^+ pumping modes of $(\text{Na},\text{K})\text{-ATPase}$; and Kotnik *et al* 2000 who explored the degree of amplification of an external electric field within the cell at various harmonic frequencies and showed the cell membrane amplifies externally applied alternating current electric fields.

In common with non-thermal pulsed radio frequency, TSE signals are thought to have direct effects on processes that occur in the central and or peripheral nervous systems, for example the behaviour of microtubules, the rate of release of certain ligands and or the responses to them by various ligand gated receptors. The signal may also have effects on the mobility of ions associated with the transmission of action potentials and act directly on other cell structures such as voltage gated channels in both the peripheral and central nervous system.

Fig 12 The energy of TSE waveforms contains multiple harmonics spread across the frequency spectrum. In this example, using half-microsecond pulses, single cycle TSE has a wide spread of energy peaking at 400 kHz, whereas burst TSE has a marked peak at 500 kHz. Both are radio frequency signals.



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