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17

Transcutaneous electrical nerve stimulation (TENS)

Mark Johnson

INTRODUCTION

Transcutaneous electrical nerve stimulation (TENS) is a simple, non-invasive analgesic technique that is used extensively in health-care settings by physiotherapists, nurses and midwifes (Johnson, 1997; Pope, Mockett and Wright, 1995; Reeve, Menon and Corabian, 1996; Robertson and Spurritt, 1998). It can be administered in the clinic by health-care professionals or at home by patients who have purchased a TENS device directly from manufacturers. TENS is mainly used for the symptomatic management of acute and non-malignant chronic pain (Box 17.1, Walsh, 1997a; Woolf and Thompson, 1994). However, TENS is also used in palliative care to manage pain caused by metastatic bone disease and neoplasm (Thompson and Filshie, 1993). It is also claimed that TENS has antiemetic and tissue-healing effects although it is used less often for these actions (Box 17.1, Walsh, 1997b).

During TENS, pulsed currents are generated by a portable pulse generator and delivered across the intact surface of the skin via conducting pads called electrodes (Fig. 17.1). The conventional way of administering TENS is to use electrical characteristics that selectively activate large diameter 'touch' fibres (Aβ) without activating smaller diameter nociceptive fibres (Aδ and C). Evidence suggests that this will produce pain relief in a similar way to 'rubbing the pain better' (see Mechanisms of action). In practice, conventional TENS is delivered to generate a

Box 17.1 Common medical conditions that TENS has been used to treat

Analgesic effects of TENS

Relief of acute pain
- Postoperative pain
- Labour pain
- Dysmenorrhoea
- Musculoskeletal pain
- Bone fractures
- Dental procedures

Relief of chronic pain
- Low back
- Arthritis
- Stump and phantom
- Postherpetic neuralgia
- Trigeminal neuralgia
- Causalgia
- Peripheral nerve injuries
- Angina pectoris
- Facial pain
- Metastatic bone pain

Non-analgesic effects of TENS

Antiemetic effects
- Postoperative nausea associated with opioid medication
- Nausea associated with chemotherapy
- Morning sickness
- Motion/travel sickness

Improving blood flow
- Reduction in ischaemia due to reconstructive surgery
- Reduction of symptoms associated with Raynaud's disease and diabetic neuropathy
- Improved healing of wounds and ulcers

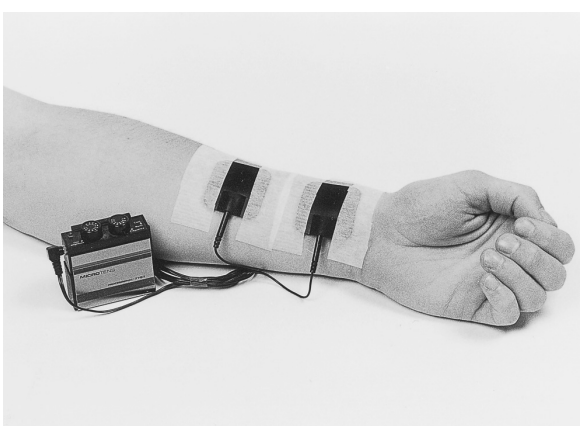

Figure 17.1 A standard device delivering TENS to the arm. There is increasing use of self-adhesive electrodes rather than black carbon-rubber electrodes that require conductive gel and tape as shown in the diagram.

strong but comfortable paraesthesia within the site of pain using frequencies between 1 and 250 pulses per second (p.p.s.) and pulse durations between 50 and 1000 μs.

In medicine, TENS is the most frequently used electrotherapy for producing pain relief. It is popular because it is non-invasive, easy to administer and has few side-effects or drug interactions. As there is no potential for toxicity or overdose, patients can administer TENS themselves and titrate the dosage of treatment as required. TENS effects are rapid in onset for most patients so benefit can be achieved almost immediately. TENS is cheap when compared with long-term drug therapy and some TENS devices are available for less than £30.00.

HISTORY

There is evidence that ancient Egyptians used electrogenic fish to treat ailments in 2500BC, although the Roman Physician Scribonius Largus is credited with the first documented report of the use of electrogenic fish in medicine in AD46 (Kane and Taub, 1975). The development of electrostatic generators in the eighteenth century increased the use of medical electricity, although its popularity declined in the nineteenth and early twentieth century due to variable clinical results and the development of alternative treatments (Stillings, 1975). Interest in the use of electricity to relieve pain was reawakened in 1965 by Melzack and Wall (1965) who provided a physiological rationale for electroanalgesic effects. They proposed that transmission of noxious information could be inhibited by activity in large diameter peripheral afferents or by activity in pain-inhibitory pathways descending from the brain (Fig. 17.2). Wall and Sweet (1967) used high-frequency percutaneous electrical stimulation to activate large diameter peripheral afferents artificially and found that this relieved chronic pain in patients. Pain relief was also demonstrated when electrical currents were used to stimulate the periaqueductal grey (PAG) region of the midbrain (Reynolds, 1969), which is part of the descending pain-inhibitory pathway. Shealy, Mortimer

and Reswick (1967) found that electrical stimulation of the dorsal columns, which form the central transmission pathway of large diameter peripheral afferents, also produced pain relief. TENS was used to predict the success of dorsal column stimulation implants until it was realised that it could be used as a successful modality on its own (Long, 1973, 1974).

DEFINITION

By definition, any stimulating device which delivers electrical currents across the intact surface of the skin is TENS, although the technical characteristics of a standard TENS device are given in Table 17.1 and Figure 17.3. Developments in electronic technology have meant that

Table 17.1 Typical features of TENS devices

Weight dimensions	50–250 g 6 × 5 × 2 cm (small device) 12 × 9 × 4 cm (large device)
Cost	£30–150
Pulse waveform (fixed)	Monophasic Symmetrical biphasic Asymmetrical biphasic
Pulse amplitude (adjustable)	1–50 mA into a 1 kΩ load
Pulse duration (often fixed)	10–1000 μs
Pulse frequency (adjustable)	1–250 p.p.s.
Pulse pattern	Continuous, burst (random frequency, modulated amplitude, modulated frequency, modulated pulse duration)
Channels	1 or 2
Batteries	PP3 (9 V), rechargeable
Additional features	Timer Most devices deliver constant current output

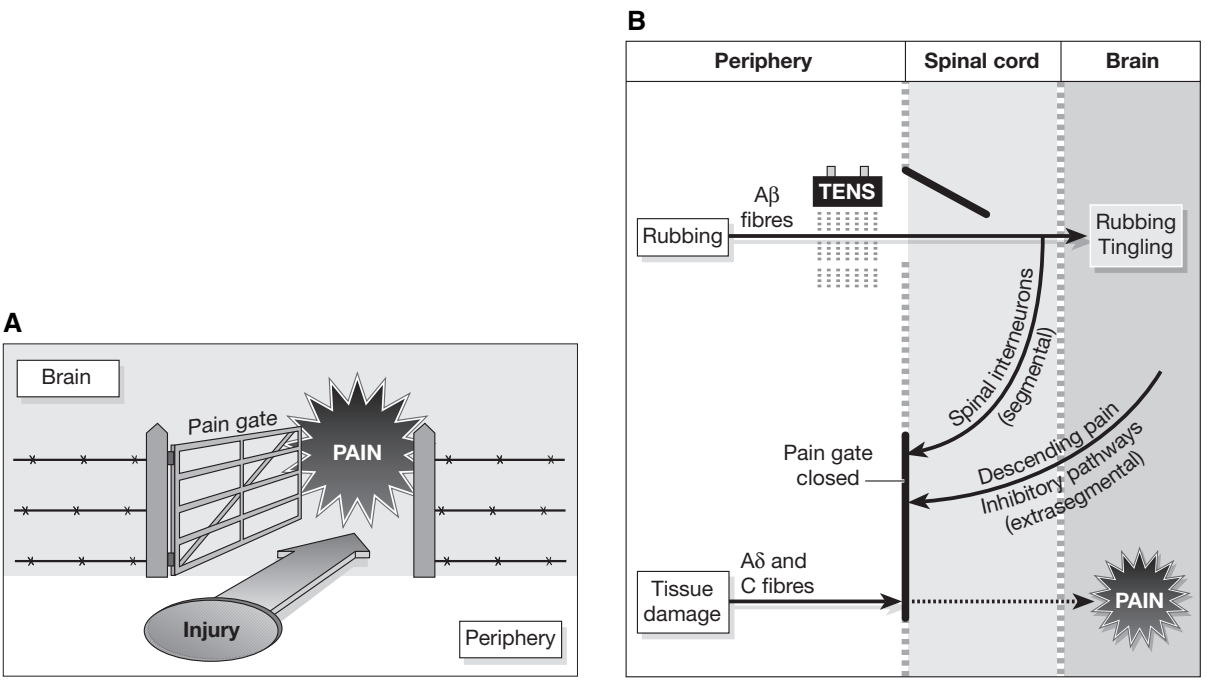

Figure 17.2 The 'Pain Gate'. A: Under normal physiological circumstances, the brain generates pain sensations by processing incoming noxious information arising from stimuli such as tissue damage. In order for noxious information to reach the brain it must pass through a metaphorical 'pain gate' located in lower levels of the central nervous system. In physiological terms, the gate is formed by excitatory and inhibitory synapses regulating the flow of neural information through the central nervous system. This 'pain gate' is opened by noxious events in the periphery. B: The pain gate can be closed by activation of mechanoreceptors through 'rubbing the skin'. This generates activity in large diameter Aβ afferents, which inhibits the onward transmission of noxious information. This closing of the 'pain gate' results in less noxious information reaching the brain reducing the sensation of pain. The neuronal circuitry involved is segmental in its organisation. The aim of conventional TENS is to activate Aβ fibres using electrical currents. The pain gate can also be closed by the activation of pain-inhibitory pathways which originate in the brain and descend to the spinal cord through the brainstem (extrasegmental circuitry). These pathways become active during psychological activities such as motivation and when small diameter peripheral fibres (Aδ) are excited physiologically. The aim of AL-TENS is to excite small diameter peripheral fibres to activate the descending pain-inhibitory pathways.

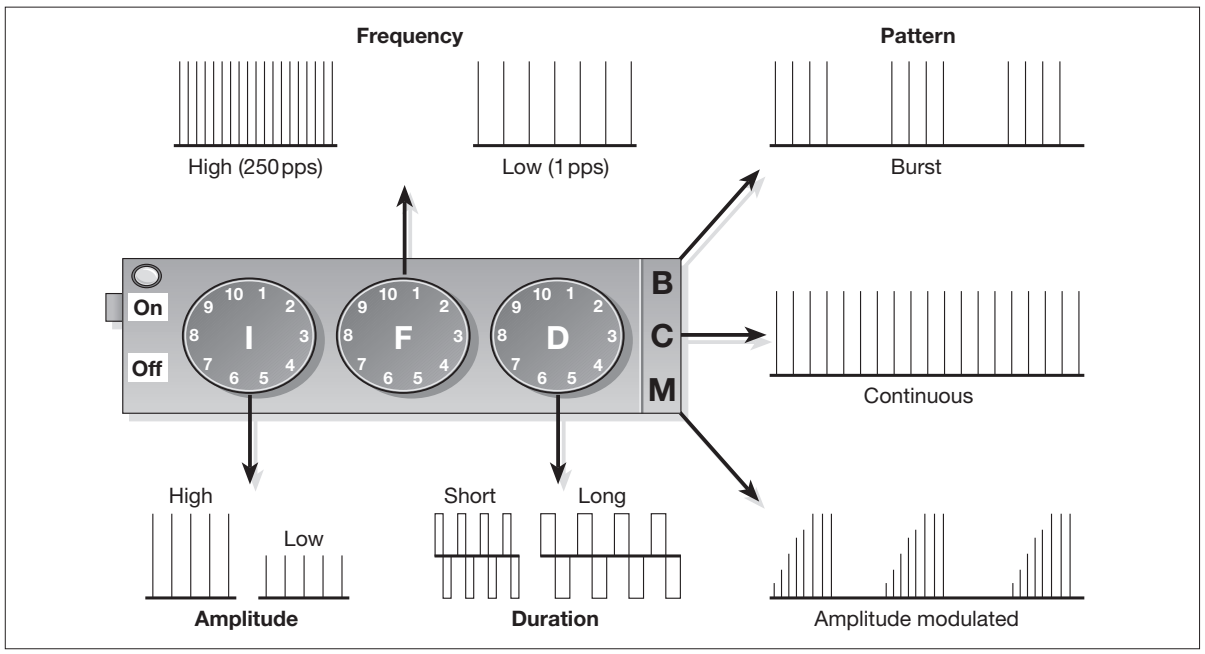

Figure 17.3 Schematic diagram of the output characteristics of a standard TENS device (topographic view, each vertical line represents one pulse). The intensity control dial (I) regulates the current amplitude of individual pulses, the frequency control dial (F) regulates the rate of pulse delivery (pulses per second = p.p.s.) and the pulse duration control dial (D) regulates the time duration of each pulse. Most TENS devices offer alternative patterns of pulse delivery such as burst, continuous and amplitude modulated.

a variety of TENS-like devices are available on the market (Table 17.2). However, the clinical effectiveness of these TENS-like devices is not known owing to a lack of randomised controlled clinical trials (RCTs). Unfortunately, the increasing number of TENS-like devices has created a literature littered with inconsistent and ambiguous terminology and this has led to confusion in nomenclature. Nevertheless, the main types of TENS described in the literature are conventional TENS, acupuncture-like TENS (AL-TENS) and intense TENS (Table 17.3, Walsh, 1997c; Woolf and Thompson, 1994). At present, conventional TENS remains the most commonly used method for delivering currents in clinical practice (Johnson, Ashton and Thompson 1991a).

PHYSICAL PRINCIPLES

The electrical characteristics of TENS are chosen with a view to selectively activate different populations of nerve fibres as this is believed to produce different analgesic outcomes (Table 17.3). A standard TENS device provides a range of possible ways that TENS currents could be delivered so it is important to review the principles of nerve fibre activation (Fig. 17.3). Large diameter nerve fibres such as Aβ and Aα have low thresholds of activation to electrical stimuli when compared with their small diameter counterparts (Aδ and C). The current amplitude needed to excite a nerve fibre declines with increasing pulse duration and increasing pulse frequency. Pulse durations of 10–1000 μs provide the greatest separation (and sensitivity) of pulse amplitudes required to selectively activate large diameter afferents, small diameter afferents and motor efferents (Fig. 17.4, Howson, 1978). Thus, to activate large diameter fibres (Aβ) without activating smaller diameter nociceptive fibres (Aδ and C) one would select low-intensity, high-frequency (10–250 p.p.s.) currents with pulse durations between 10 and 1000 μs (see Howson, 1978; Walsh, 1997d; Woolf and Thompson, 1994

Table 17.2 Characteristics of TENS-like devices

Device	Experimental work	Manufacturers claim	Typical stimulating characteristics
Action potential simulation (APS)	Odendaal and Joubert (1999)	Pain relief Improve mobility Improve circulation Reduce inflammation	Monophasic square pulse with exponential decay Delivered by two electrodes Pulse amplitude low (< 25 mA), duration long (800 μs–6.6 ms), frequency fixed at 150 p.p.s
Codetron	Pomeranz and Niznick (1987) Fargas-Babjak *et al*. (1989; 1992).	Pain relief Reduce habituation	Square wave Delivered randomly to one of six electrodes Pulse amplitude low, duration long (1 ms), frequency low (2 p.p.s.)
H wave stimulation	McDowell *et al*. (1995; 1999)	Pain relief Improve mobility Improve circulation Reduce inflammation Promote wound healing	'Unique' biphasic wave with exponential decay Delivered by two electrodes Pulse amplitude low (< 10 mA), duration long (fixed at 16 ms), frequency low (2–60 p.p.s.)
Interference currents	See Chapter 18	Pain relief Improve mobility Improve circulation Reduce inflammation Promote wound healing Muscle re-education	Two out-of-phase currents which interfere with each other to produce an amplitude-modulated wave Traditionally, delivered by four electrodes Pulse amplitude low, amplitude-modulated frequency 1–200 Hz (carrier wave frequencies approximately 2–4 kHz)
Microcurrent	Johannsen *et al*. (1993) Johnson *et al*. (1997)	Promote wound healing Pain relief Other indications often claimed	Modified square direct current with monophasic or biphasic pulses changing polarity at regular intervals (0.4 s) Delivered by two electrodes Pulse amplitude low (1–600 μA with no paraesthesia), frequency depends on manufacturer (1–5000 p.p.s.) Many variants exist (e.g. transcranial stimulation for migraine and insomnia)
Transcutaneous spinal electroanalgesia (TSE)	Macdonald and Coates (1995)	Pain relief, especially allodynia and hyperalgesia due to central sensitisation	Differentiated wave Delivered by two electrodes positioned on spinal cord at T1 and T12 or straddling C3–C5 Pulse amplitude high (although no paraesthesia), duration very short (1.5–4 μs, frequency high (600–10 000 p.p.s.)

for discussion). Increasing the pulse duration will lead to the activation of small diameter fibres at lower pulse amplitudes.

In practice, it is difficult to predict the exact nature and distribution of currents when they are passed across the intact surface of the skin due to the complex and non-homogeneous impedance of the tissue. However, as the skin offers high impedance at pulse frequencies used by TENS it is likely that currents will remain superficial stimulating cutaneous nerve fibres rather than deep-seated visceral and muscle nerve fibres. Moreover, different TENS devices use a variety of pulse waveforms. Generally, these can be divided into monophasic and biphasic waveforms (Fig. 17.5). It is the cathode (usually the black lead) that excites the axon so in practice the cathode is placed proximal to the anode to prevent the blockade of nerve transmission due to hyperpolarisation (Fig. 17.6). Devices which use biphasic waveforms with zero net current flow will alternate the cathode and anode between the two electrodes. Zero net current flow may prevent the build-up of ion concentrations beneath electrodes, preventing adverse skin reactions due to polar concentrations (Kantor, Alon and Ho, 1994; Walsh, 1997d).

The introduction of novel features on devices, such as modulated amplitude, modulated frequency and modulated duration (Fig. 17.7), enable manufacturers to gain a competitive edge in the market-place but are rarely supported by

Table 17.3 The characteristics of different types of TENS

	Aim of currents	Main fibre-type responsible for effects	Desired outcome—patient experience	Optimal electrical characteristics	Electrode position	Analgesic profile	Duration of treatment	Main mechanism of analgesic action
Conventional TENS	Activate large diameter non-noxious cutaneous afferents	Aβ, mechano-receptors	Strong comfortable electrical paraesthesia with minimal muscle activity	High frequency/ low intensity Amplitude = low Duration = 100–200 μs Frequency= 10–200 p.p.s. Pattern = continuous	Over site of pain Dermatomal	Rapid onset < 30 min after switch-on Rapid offset < 30 min after switch-off	Continuously when in pain	Segmental
AL-TENS	Activate motor efferents to produce phasic muscle twitch leading to activation of small diameter non-noxious muscle afferents (GIII)	GIII, Aδ ergoreceptors	Strong comfortable phasic muscle contraction	Low frequency/ high intensity Amplitude = high Duration = 100–200 μs Frequency = ~ 100 p.p.s. within burst Pattern = burst	Over motor point/ muscle at site of pain Myotomal	?Delayed onset > 30 min after switch-on ?Delayed offset > 1 h after switch-off	~ 30 min/ session	Extrasegmental Segmental
Intense TENS	Activate small diameter 'pin-prick' cutaneous afferents	Aδ, nociceptors	Highest intensity tolerable with minimal muscle contraction	High frequency / high intensity Amplitude = highest tolerable Duration > 1000 μs Frequency = ~ 200 p.p.s. Pattern = continuous	Over site of pain or proximal over main nerve bundle	Rapid onset < 30 min after switch-on ?Delayed offset > 1 h after switch-off May experience hypoaesthesia	~ 15 min/ session	Peripheral Extrasegmental Segmental

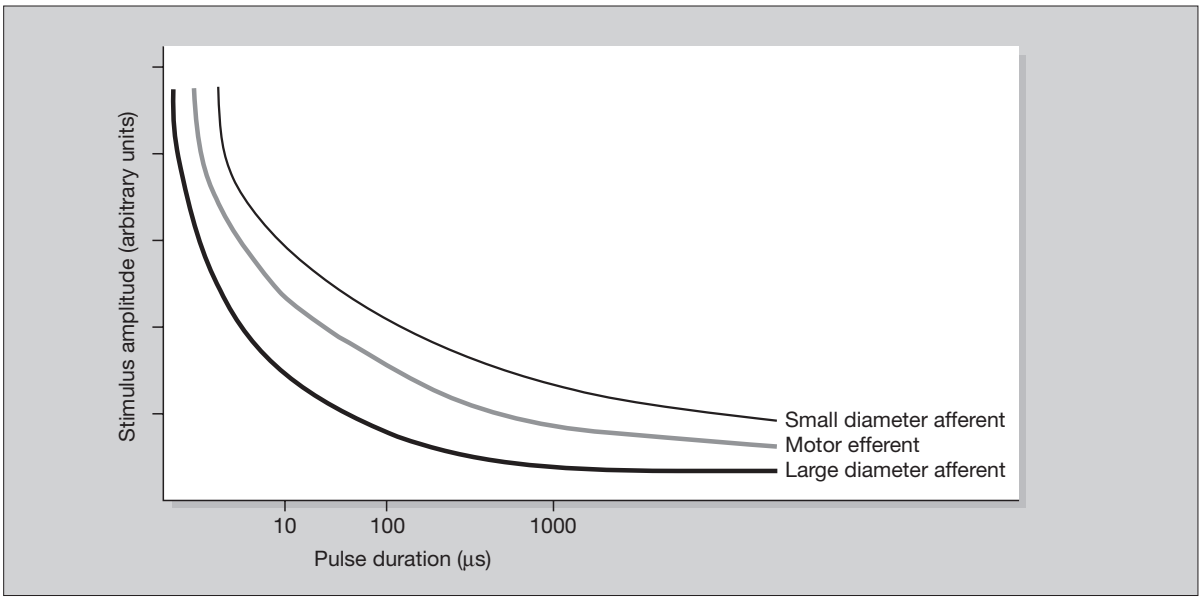

Figure 17.4 Strength–duration curve for fibre activation. As pulse duration increases less current amplitude is needed to excite an axon to generate an action potential. Small pulse durations are unable to excite nerve axons even at high current amplitudes. Large diameter axons require lower current amplitudes than small diameter fibres. Thus, passing pulsed currents across the surface of the skin excites large diameter non-noxious sensory nerves first (paraesthesia), followed by motor efferents (muscle contraction) and small diameter noxious afferents (pain). Alteration of pulse duration is one means of helping the selective recruitment of different types of nerve fibre. For example, intense TENS should use long pulse durations ($>1000\,\mu s$) as they activate small diameter afferents more readily. During conventional TENS pulse durations ~ 100–200 μs are used as there is a large separation (difference) in the amplitude needed to recruit different types of fibre. This enables greater sensitivity when using the intensity (amplitude) dial so that a strong but comfortable paraesthesia can be achieved without muscle contraction or pain.

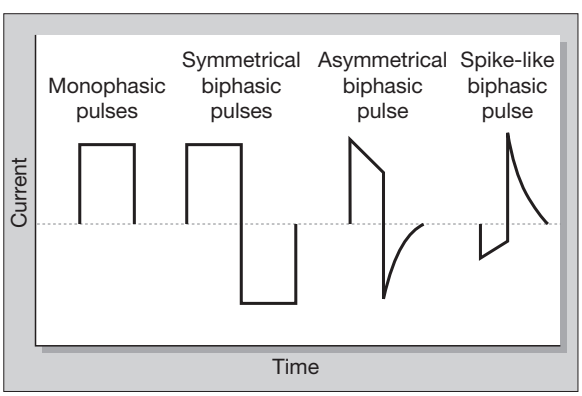

Figure 17.5 Common pulse waveforms used in TENS.

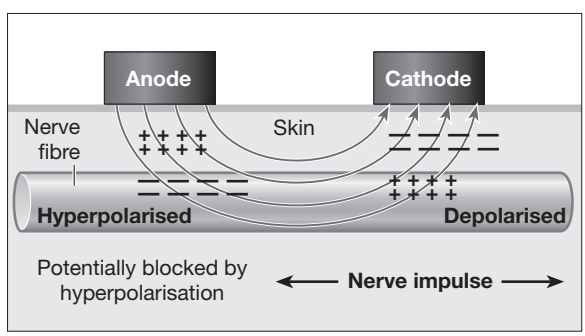

Figure 17.6 Fibre activation by TENS. When devices use waveforms which produce net DC outputs which are not zero, the cathode excites (depolarisation) the axon and the nerve impulse will travel in both directions down the axon. The anode tends to inhibit the axon (hyperpolarisation) and this could extinguish the nerve impulse. Thus, during conventional TENS the cathode should be positioned proximal to the anode so that the nerve impulse is transmitted to the central nervous system unimpeded. However, during AL-TENS the cathode should be placed distal, or over the motor point, as the purpose of AL-TENS currents is to activate a motor efferent.

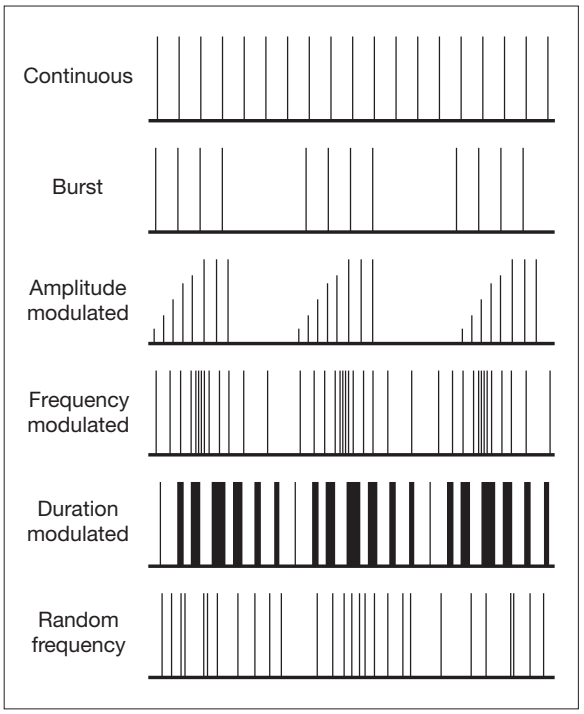

Figure 17.7 Novel pulse patterns available on TENS devices. Modulated patterns fluctuate between upper and lower limits over a fixed period of time and this is usually preset in the design of the TENS device.

proven improvements in clinical effectiveness. Unfortunately, the ever-increasing complexity of TENS devices has led to confusion about the most appropriate way to administer TENS. Therefore it is important to summarise the principles for the main types of TENS.

Conventional TENS

The aim of conventional TENS is to activate selectively large diameter Aβ fibres without concurrently activating small diameter Aδ and C (pain-related) fibres or muscle efferents (Fig. 17.8). Evidence from animal and human studies supports the hypothesis that conventional TENS produces segmental analgesia with a rapid onset and offset and which is localised to the dermatome (see Mechanisms of action). Theoretically, high-frequency, low-intensity pulsed currents would be most effective in selectively activating

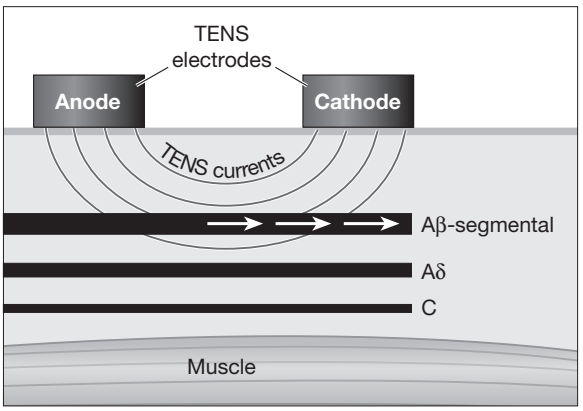

Figure 17.8 The aim of conventional TENS is to selectively activate Aβ afferents producing segmental analgesia.

large diameter fibres, although in practice this will be achieved whenever the TENS user reports that they experience a comfortable paraesthesia beneath the electrodes.

During conventional TENS currents are usually delivered between 10 and 200 p.p.s., and 100–200 μs with pulse amplitude titrated to produce a strong comfortable and non-painful paraesthesia (Table 17.3). As large diameter fibres have short refractory periods they can generate nerve impulses at high frequencies. This means that they are more able to generate high-frequency volleys of nerve impulses when high-frequency currents are delivered. Thus, greater afferent barrages will be produced in large diameter nerve fibres when high frequencies (10–200 p.p.s.) are used. The pattern of pulse delivery is usually continuous, although conventional TENS can also be achieved by delivering the pulses in 'bursts' or 'trains' and this has been described by some authors as pulsed or burst TENS (Walsh, 1997c; Woolf and Thompson, 1994). It is likely that continuous TENS and burst TENS produce similar effects when delivered at a strong but comfortable level without concurrent muscle twitches.

Acupuncture-like TENS (AL-TENS)

The majority of commentators believe that AL-TENS should be defined as the induction of forceful but non-painful phasic muscle contractions

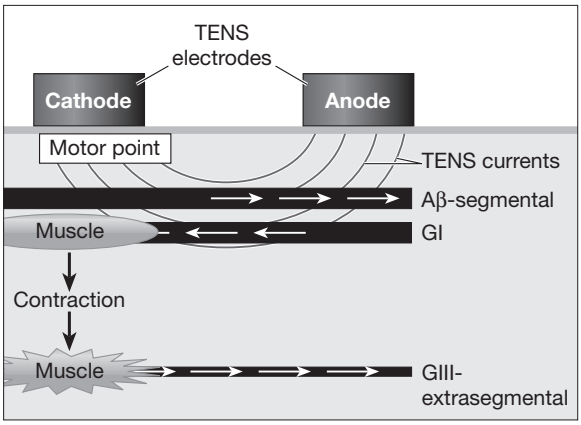

Figure 17.9 The aim of AL-TENS is to selectively activate group I (GI) efferents producing a muscle contraction, which results in activity in ergoreceptors and group III (GIII) afferents. GIII afferents are small in diameter and have been shown to produce extrasegmental analgesia through the activation of descending pain inhibitory pathways. Aβ afferents will also be activated during AL-TENS producing segmental analgesia. Note the position of the cathode.

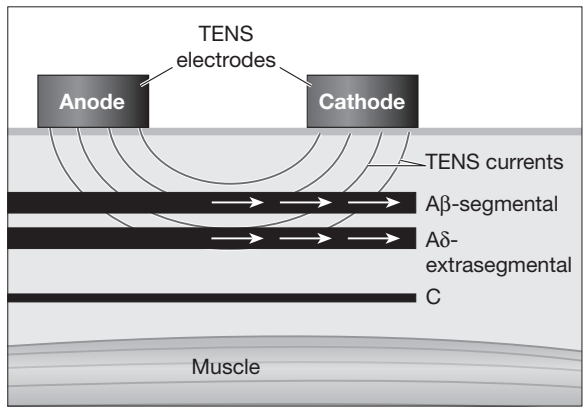

Figure 17.10 The aim of intense TENS is to selectively activate Aδ afferents leading to extrasegmental analgesia. Aβ afferents will also be activated producing segmental analgesia.

at myotomes related to the origin of the pain (Eriksson and Sjölund, 1976; Johnson, 1998; Meyerson, 1983; Sjölund, Eriksson and Loeser, 1990; Walsh, 1997c; Woolf and Thompson, 1994). The purpose of AL-TENS is to selectively activate small diameter fibres (Aδ or group III) arising from muscles (ergoreceptors) by the induction of phasic muscle twitches (Fig. 17.9). Thus, TENS is delivered over motor points to activate Aα efferents to generate a phasic muscle twitch resulting in ergoreceptor activity (Table 17.3). Patients report discomfort when low-frequency pulses are used to generate muscle twitches so bursts of pulses are used instead (Eriksson and Sjölund, 1976). Evidence suggests that AL-TENS produces extrasegmental analgesia in a manner similar to that suggested for acupuncture (see Mechanisms of action). However, there is inconsistency in the use of the term, 'AL-TENS', as some commentators describe AL-TENS as the delivery of TENS over acupuncture points irrespective of muscle activity (Lewers *et al*., 1989; Lewis *et al*., 1990; Longobardi *et al*., 1989; Rieb and Pomeranz, 1992). A critical review of AL-TENS can be found in Johnson (1998).

Intense TENS

The aim of intense TENS is to activate small diameter Aδ cutaneous afferents by delivering TENS over peripheral nerves arising from the site of pain at an intensity which is just tolerable to the patient (Jeans, 1979; Melzack, Vetere and Finch, 1983, Fig. 17.10). Thus, TENS is delivered over the site of pain or main nerve bundle arising from the pain using high-frequency and high-intensity currents which are just bearable to the patient (Table 17.3). As intense TENS acts in part as a counterirritant it can be delivered for only a short time but it may prove useful for minor surgical procedures such as wound dressing and suture removal. Activity in cutaneous Aδ afferents induced by intense TENS has been shown to produce peripheral blockade of nociceptive afferent activity and segmental and extrasegmental analgesia (see Mechanisms of action).

Practical implications

The theoretical relationship between pulse frequency, duration and pattern may break down as currents follow the path of least resistance through the underlying tissue. So in clinical practice a trial and error approach is used whereby patients titrate current amplitude, frequency and duration to produce the appropriate

outcome. The patients' report of the sensation produced by TENS is the easiest means of assessing the type of fibre active. A strong non-painful electrical paraesthesia is mediated by large diameter afferents and a mildly painful electrical paraesthesia is mediated by recruitment of small diameter afferents. The presence of a strong non-painful phasic muscle contraction is likely to excite muscle ergoreceptors.

KNOWN BIOLOGICAL EFFECTS

TENS effects can be subdivided into analgesic and non-analgesic effects (Box 17.1). In clinical practice, TENS is predominantly used for its symptomatic relief of pain although there is increasing use of TENS as an antiemetic and for restoration of blood flow to ischaemic tissue and wounds. There is, however, less published research on the non-analgesic effects of TENS and some of the experimental work in the field is contradictory. The reader is guided to Walsh (1997b) for a discussion of the non-analgesic effects of TENS. In contrast, the mechanism by which TENS produces pain relief has received much attention.

Mechanisms of action

Stimulation-induced analgesia can be categorised according to the anatomical site of action into peripheral, segmental and extrasegmental. In general, the main action of conventional TENS is segmental analgesia mediated by Aβ fibre activity. The main action of AL-TENS is extrasegmental analgesia mediated by ergoreceptor activity. The main action of intense TENS is extrasegmental analgesia via activity in small diameter cutaneous afferents. Conventional and intense TENS are also likely to produce peripheral blockade of afferent information in the fibre type that they activate.

Peripheral mechanisms

The delivery of electrical currents over a nerve fibre will elicit nerve impulses that travel in both directions along the nerve axon, termed antidromic activation (Fig. 17.11). TENS-induced nerve impulses travelling away from the central nervous system will collide with and extinguish afferent impulses arising from tissue damage. For conventional TENS, antidromic activation is likely to occur in large diameter fibres and as tissue damage may produce some activity in large diameter fibres conventional TENS may mediate some of its analgesia by peripheral blockade in large diameter fibres. TENS-induced blockade of peripheral nerve transmission has been demonstrated by Walsh *et al*. (1998) in healthy human subjects. They found that TENS delivered at 110 p.p.s. significantly increased the negative peak latency of the compound action potential and this suggests that there was a slowing of transmission in the peripheral nerve. Nardone and Schieppati (1989) have also reported that the latency of early somatosensory evoked potentials (SEPs) was increased during TENS in healthy subjects and concluded that conventional TENS could produce a 'busy line-effect' in large afferent fibres.

The contribution of peripheral blockade on analgesia is likely to be greater during intense TENS. Impulses travelling in Aδ fibres induced

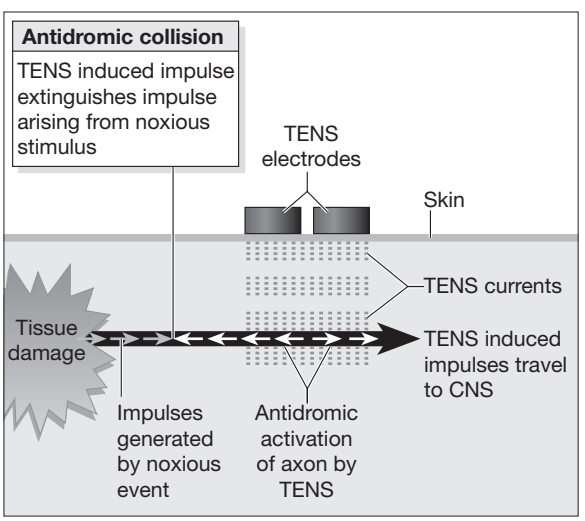

Figure 17.11 TENS-induced blockade of peripheral transmission. Impulses generated by TENS will travel in both directions down an axon (antidromic activation) leading to a collision with noxious impulses travelling toward the central nervous system (CNS).

by intense TENS will collide with nociceptive impulses, also travelling in Aδ fibres. Ignelzi and Nyquist (1976) demonstrated that electrical stimulation (at intensities likely to recruit Aδ fibres) can reduce the conduction velocity and amplitude of Aα, Aβ and Aδ components of the compound action potential recorded from isolated nerves in the cat. The greatest change was found in the Aδ component. However, Levin and Hui-Chan (1993) have shown that healthy subjects cannot tolerate direct activation of Aδ afferents by TENS and therefore intense TENS is administered for only brief periods of time in clinical practice.

Segmental mechanisms

Conventional TENS produces analgesia predominantly by a segmental mechanism whereby activity generated in Aβ fibres inhibits ongoing activity in second-order nociceptive (pain related) neurons in the dorsal horn of the spinal cord (Fig. 17.12). Workers have shown that activity in large diameter afferents will inhibit nociceptive reflexes in animals when the influence of pain-inhibitory pathways descending from the brain has been removed by spinal transection (Sjölund, 1985; Woolf, Mitchell and Barrett, 1980; Woolf, Thompson and King, 1988). Garrison and Foreman (1994) showed that TENS could significantly reduce ongoing nociceptor cell activity in the dorsal horn cell when it was applied to somatic receptive fields. Follow-up work after spinal cords had been transected at T12 demonstrated that spontaneously and noxiously evoked cell activities were still reduced during TENS. This demonstrates that the neuronal circuitry for conventional TENS analgesia is located in the spinal cord and it is likely that a combination of pre- and postsynaptic inhibition takes place (Garrison and Foreman, 1996).

Studies using the opioid receptor antagonist naloxone have failed to reverse analgesia from high-frequency TENS, suggesting that non-opioid transmitters may be involved in this synaptic inhibition (see Thompson (1989) for review). Studies by Duggan and Foong (1985) using anaesthetised cats suggest that the

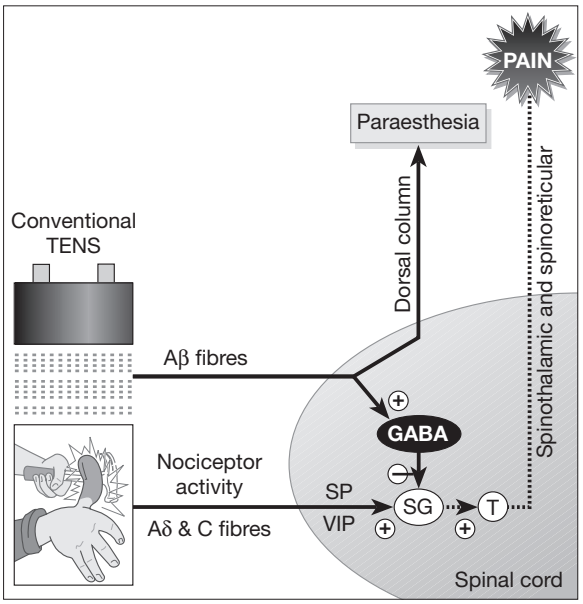

Figure 17.12 Neurophysiology of conventional TENS analgesia. Activity in Aδ and C fibres from nociceptors leads to excitation (+) of interneurons in the substantia gelatinosa (SG) of the spinal cord via neurotransmitters like substance P (SP, cutaneous nociceptors) or vasoactive intestinal peptide (VIP, visceral nociceptors). Central nociceptor transmission neurons (T) project to the brain via spinoreticular and spinothalamic tracts to produce a sensory experience of pain. TENS-induced activity in Aβ afferents leads to the inhibition (–) of SG and T cells (dotted line) via the release of gamma amino butyric acid (GABA, black interneuron). Paraesthesia associated with TENS is generated by information travelling to the brain via the dorsal columns.

inhibitory neurotransmitter gamma aminobutyric acid (GABA) may play a role. The clinical observation that conventional TENS produces analgesia that is short lasting and rapid in onset is consistent with synaptic inhibition at a segmental level.

A number of workers have shown that TENS-induced activity in Aδ fibres during intense TENS can lead to long-term depression (LTD) of central nociceptor cell activity for up to 2 hours. Low-frequency stimulation of Aδ-fibres (1 p.p.s., 0.1 ms) has been shown to produce LTD in animals which is not influenced by bicuculline, which is a GABA receptor antagonist, but is abolished by D-2-amino-5-phosphonovaleric acid, which is a *N*-methyl-D-aspartate (NMDA) receptor antagonist (Sandkühler, 2000; Sandkühler

et al., 1997). This suggests that glutamate rather than GABA may be involved in LTD induced by intense TENS. The time course of latency and amplitude changes in SEPs after high-frequency (200 p.p.s.) electrical stimulation of the digital nerves in healthy subjects supports the concept that TENS can produce LTD of central nociceptive cells (Macefield and Burke, 1991). One practical outcome of this work may be introduction of 'sequential TENS' where conventional TENS is administered at a strong but comfortable level in the first instance followed by a brief period of intense TENS leading to longer post-stimulation analgesia (Sandkühler, 2000).

Extrasegmental mechanisms

TENS-induced activity in small diameter afferents has also been shown to produce extrasegmental analgesia through the activation of structures which form the descending pain-inhibitory pathways, such as periaqueductal grey (PAG), nucleus raphe magnus and nucleus raphe gigantocellularis. Antinociception in animals produced by stimulation of cutaneous Aδ fibres is reduced by spinal transection, suggesting a role for extrasegmental structures (Chung *et al*., 1984a, b; Woolf, Mitchell and Barrett, 1980). Phasic muscle contractions produced during AL-TENS generates activity in small diameter muscle afferents (ergoreceptors) leading to activation of the descending pain-inhibitory pathways (Fig. 17.13). The importance of muscle afferent activity in this effect has been shown in animal studies by Sjölund (1988) who found that greater antinociception occurred when muscle rather than skin afferents were activated by low-frequency (2 bursts per second) TENS. Duranti, Pantaleo and Bellini (1988) confirmed this in humans by demonstrating that there was no difference in analgesia produced by currents delivered through the skin (e.g. AL-TENS) compared to currents which by passed the skin (e.g. intramuscular electrical nerve stimulation; IENS).

There is growing evidence that AL-TENS but not conventional TENS is mediated by endorphins. Sjölund, Terenius and Eriksson, (1977) reported that AL-TENS increased cerebrospinal (CSF) endorphin levels in nine patients suffering chronic pain and that AL-TENS analgesia was naloxone reversible (Sjölund and Eriksson, 1979). However, naloxone failed to reverse analgesia produced by conventional TENS in pain patients (Abram, Reyolds and Cusick, 1981; Hansson *et al*., 1986; Woolf *et al*, 1978). Claims that conventional TENS can elevate plasma β-endorphin and β-lipotrophin in healthy subjects (Facchinetti *et al*., 1986) have not been confirmed (Johnson *et al*., 1992) and it seems unlikely that β-endorphin would cross the blood–brain barrier owing to its large size.

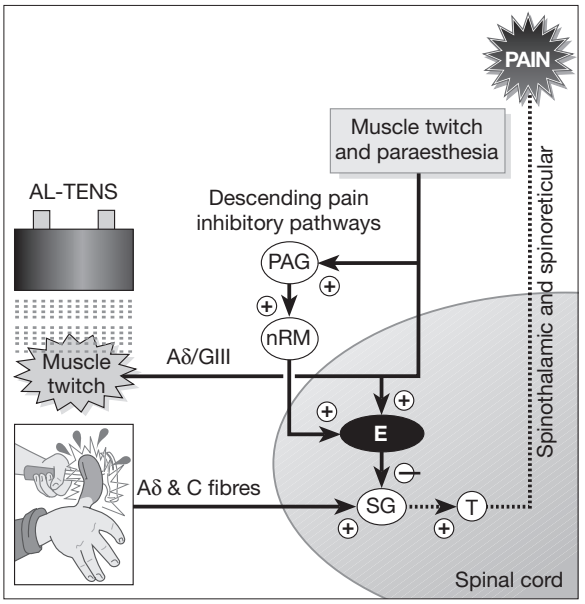

Figure 17.13 Neurophysiology of AL-TENS analgesia. Actvity in Aδ and C fibres from nociceptors leads to excitation (+) of central nociceptor transmission neurons (T) which project to the brain to produce a sensory experience of pain. TENS-induced activity in small diameter muscle afferents (Aδ, GIII) leads to the activation of brainstem nuclei such as the periaqueductal grey (PAG) and nucleus raphe magnus (nRM). These nuclei form the descending pain inhibitory pathways which excite interneurons which inhibit (–) SG and T cells (dotted line) via the release of met-enkephalin (E, black interneuron). It is likely that paraesthesia and sensations related to the muscle twitch are relayed to the brain via the dorsal columns.

Analgesic effects

As different mechanisms contribute to analgesia produced by different types of TENS it is plausible that they will have different analgesic profiles. In fact this is the rationale for the use of different types of TENS. Evidence from laboratory and clinical studies show that TENS analgesia is maximal when the stimulator is switched on irrespective of the type of TENS used (Fishbain *et al.*, 1996; Johnson *et al.*, 1991a; Walsh, 1997c; Woolf and Thompson 1994). This explains the finding that long-term users of TENS administer conventional TENS continuously throughout the day to achieve adequate analgesia (Chabal *et al.*, 1998; Fishbain *et al.*, 1996; Johnson *et al.*, 1991a; Nash, Williams and Machin, 1990). Poststimulation analgesia has been reported to occur in some patients and this may be due to LTD and activation of descending pain inhibitory pathways. Reports of the duration of these poststimulation effects vary widely from 18 hours (Augustinsson, Carlsson and Pellettieri, 1976) to 2 hours (Johnson *et al.*, 1991a). It is possible that natural fluctuations in symptoms and the patient's expectation of treatment effects may have contributed to some extent to these observations.

There are remarkably few studies which have systematically investigated the analgesic profiles of a range of TENS pulse frequencies, pulse durations and pulse patterns when all other stimulating characteristics are fixed. There is an extensive literature of studies which have compared the analgesic effects of two pulse frequencies (usually high ~100 p.p.s. and low ~2 p.p.s.) in animals, healthy humans and patients in pain. However, the TENS characteristics used in many of these studies appear to have been chosen ad hoc, which makes synthesis of the findings between groups almost impossible (see tables in Walsh 1997a and e).

Sjölund (1985) delivered seven different stimulation frequencies (10, 40, 60, 80, 100, 120 and 160 p.p.s.) to a dissected skin nerve in lightly anaesthetised rats and reported that a stimulation frequency of 80 p.p.s. gave the most profound inhibition of the C-fibre-evoked flexion reflex. In a follow-up study they reported that a pulse-train repetition rate of around 1 Hz was most effective in inhibition of the C-fibre-evoked flexion reflex. Johnson *et al*. (1989) assessed the analgesic effects of five stimulating frequencies (10, 20, 40, 80 and 160 p.p.s.) on cold-induced pain in healthy subjects. TENS frequencies between 20 and 80 p.p.s. produced greatest analgesia when delivered at a strong but comfortable intensity, with 80 p.p.s. producing the least intersubject variation in response (e.g. the most reliable effect among subjects). Thus, when trying out conventional TENS on a patient for the first time it seems sensible to start with frequencies around 80 p.p.s.

Johnson *et al*. (1991) systematically investigated the analgesic effects of burst, amplitude-modulated, random (frequency of pulse delivery) and continuous TENS delivered at a strong but comfortable level on cold-induced pain in healthy subjects. All pulse patterns elevated ice-pain threshold but there were no significant differences between the groups when all other stimulating characteristics were fixed. Tulgar *et al*. (1991a) demonstrated that a variety of patterns of pulse delivery were equally effective in managing patients' pain. However, patients preferred modulated patterns of TENS such as frequency modulation and burst rather than continuous (Tulgar *et al*., 1991b). This seems to contrast with Johnson, Ashton and Thompson (1991a) who found that the majority of long-term users of TENS preferred continuous rather than burst mode. More systematic investigations which compare the analgesic effects of a range of (i.e. more than two) stimulating characteristics when all other variables are fixed are clearly needed.

KNOWN EFFICACY: THE CLINICAL EFFECTIVENESS OF TENS

There is an extensive literature on the clinical effectiveness of TENS although the majority of reports are anecdotal or of clinical trials lacking appropriate control groups. These reports are of limited use in determining the clinical effectiveness as they do not take account of normal

fluctuations in the patient's symptoms, the treatment effects of concurrent interventions or the patient's expectation of treatment success. Placebo-controlled clinical trials should be used to determine the absolute effectiveness of treatments so that the effects due to the active ingredient (e.g. the electrical currents for TENS) can be isolated from the effects associated with the act of giving the treatment. Placebo or sham TENS is usually achieved by preventing TENS currents from reaching the patient, for example by cutting wires within the device. Failure to blind patients and investigators to the different treatment groups in placebo-controlled trials, as well as failure to randomise the sample population into treatment groups, will markedly overestimate treatment effects (see McQuay and Moore, 1998a; Schulz *et al.*, 1995 for discussion). Unfortunately, there are many practical difficulties in designing and blinding treatment groups in studies which examine technique-based interventions like TENS (Bjordal and Greve, 1998; Deyo *et al.*, 1990a; Thorsteinsson, 1990).

Carroll *et al*. (1996) demonstrated the impact of using non-randomised trials in determining TENS effectiveness; 17 of 19 non-randomised controlled trials (non-RCTs) reported that TENS had a positive analgesic effect whereas 15 of 17 randomised controlled trials (RCTs) reported that TENS had no effect for postoperative pain. Carroll *et al*. (1996) concluded that non-randomised studies on TENS, or any other treatment, will overestimate treatment effects. Therefore, in a climate of evidence-based medicine the findings of systematic reviews of randomised controlled clinical trials will be used to determine effectiveness (Table 17.4).

Table 17.4 Outcomes of systematic reviews

Condition	Existing reviews
Acute pain	Reeve, Menon and Corabian (1996) Range of conditions (dysmenorrhea, dental, cervical, orofacial, sickle cell disease) TENS effective 7/14 RCTs Reviewers conclusion: evidence inconclusive—poor RCT methodology in field
Postoperative pain	Reeve, Menon and Corabian (1996) TENS effective 12/20 RCTs Reviewers conclusion: evidence inconclusive—poor RCT methodology in field
	Carroll *et al*. (1996) TENS effective in 2/17 RCTs Reviewers conclusion: limited evidence of effectiveness
Labour pain	Reeve, Menon and Corabian (1996) TENS effective 3/9 RCTs Reviewers conclusion: evidence inconclusive—poor RCT methodology in field
	Carroll *et al*. (1997a) TENS effective 3/8 RCTs Reviewers conclusion: limited evidence of effectiveness
	Carroll *et al*. (1997b—update of Carroll *et al*. (1997a) review) TENS effective 3/10 RCTs Reviewers conclusion: limited evidence of effectiveness
Chronic pain	Reeve, Menon and Corabian (1996) Range of conditions (low back, pancreatitis, arthritis, angina) TENS effective 9/20 RCTs Reviewers conclusion: evidence inconclusive—poor RCT methodology in field
	McQuay and Moore (1998b) Range of conditions (low back, pancreatitis, osteoarthritis, dysmenorrhea) TENS effective 10/24 RCTs Reviewers conclusion: evidence inconclusive—poor RCT methodology in field TENS dosage too low
	Flowerdew and Gadsby (1997)/ Gadsby and Flowerdew (1997) Low back pain (6 RCTs) Odds ratio vs. placebo, conventional TENS (1.62), AL-TENS (7.22) Reviewers conclusion: TENS effective—poor RCT methodology in field

TENS and acute pain

Postoperative pain

Hymes *et al*. (1974) were the first to report the success of conventional TENS for acute pain resulting from surgery using sterile electrodes straddling the incision (Fig. 17.14). Potentially, TENS could relieve pain and reduce concurrent opioid consumption and associated adverse

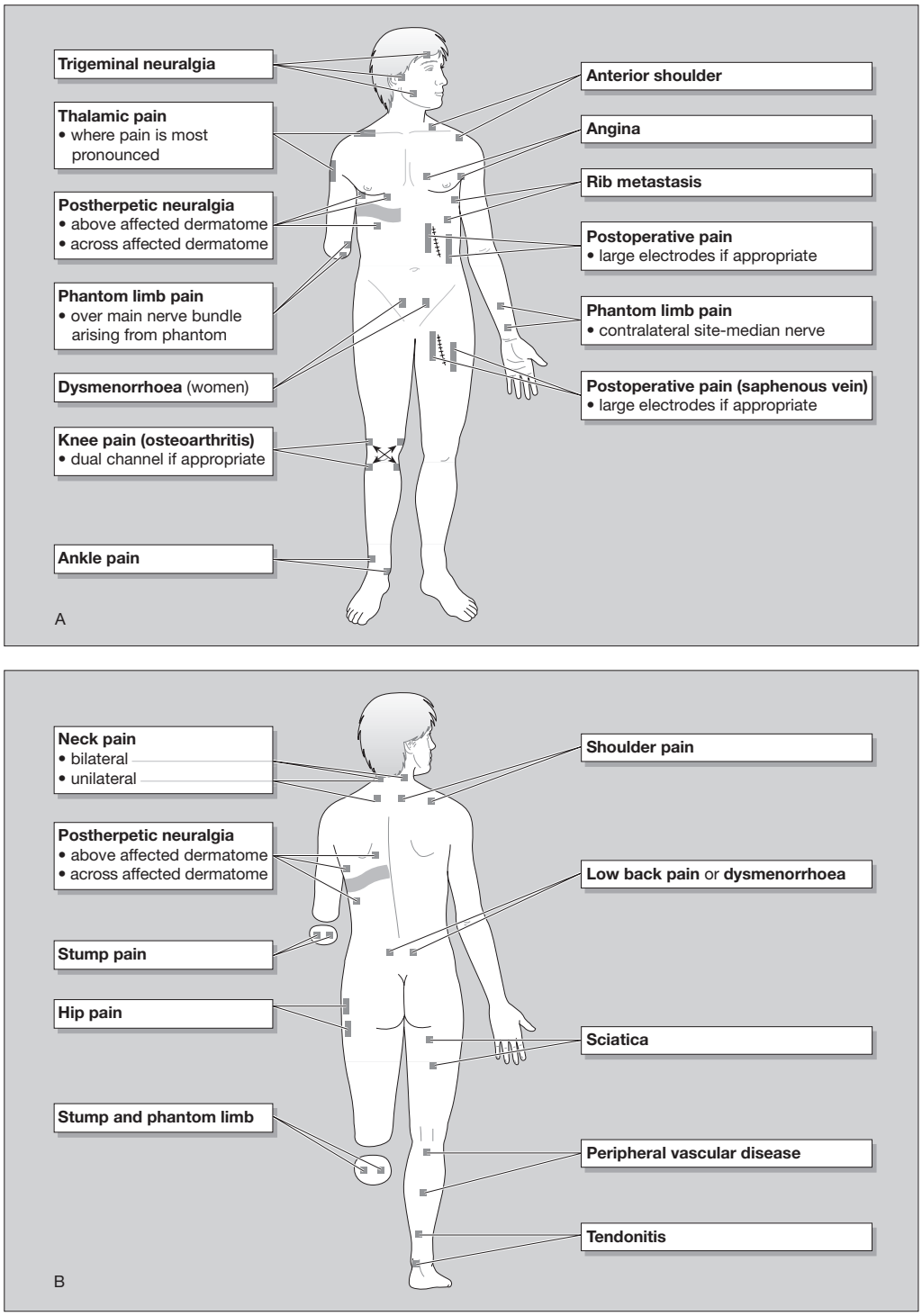

Figure 17.14 A: Electrode positions for common pain conditions—anterior view. B: Electrode positions for common pain conditions—posterior view.

events such as respiratory depression. Clinical trials have shown that TENS reduces pain and additional analgesic intake and improves respiratory function (Ali, Yaffe and Serrette, 1981; Bayindir *et al*., 1991; Benedetti *et al*., 1997; Chiu *et al*., 1999; Schuster and Infante, 1980; Warfield, Stein and Frank, 1985). However, the existing literature has been reviewed systematically by Carroll *et al*. (1996) who found that 15 of 17 RCTs reported that TENS produced no significant benefit when compared with placebo; this group concluded that TENS was not effective for the management of postoperative pain. A systematic review on acute pain, including postoperative pain, by Reeve, Menon and Corabian (1996) reported that 12 of 20 RCTs found that TENS was beneficial in postoperative pain, suggesting that TENS may be of some benefit (Table 17.4).

Closer examination reveals discrepancies in the judgements of individual RCT outcome by the reviewers, which may undermine confidence in their findings. For example, the RCT by Conn *et al*. (1986) was judged as a negative outcome study by Carroll *et al*. (1996) and a positive outcome study by Reeve, Menon and Corabian (1996). Conn *et al*. (1986) concluded that *'its (TENS) use in this situation (postappendicectomy pain) cannot be recommended'*. Difficulties in making judgements about trial outcome may arise when multiple outcome measures have been used, leading to combinations of positive and negative effects. This makes summary judgements of effectiveness by reviewers difficult. In addition, Benedetti *et al*. (1997) has shown that TENS was effective for mild to moderate pain associated with thoracic surgical procedures but ineffective for severe pain. However, reductions in mild pain are harder to detect than reductions in severe pain, and studies which include only those patients with mild to moderate pain will lose sensitivity in the detection of outcome measure, while TENS trials attempting to optimise trial sensitivity by including only patients with severe pain would bias the study toward negative outcome. This may be overlooked in systematic reviews, so it would be hasty to accept the findings of the systematic reviews on TENS and postoperative pain without further scrutiny (Bjordal and Greve, 1998; Johnson, 2000).

Labour pain

The popularity of TENS for labour pain is due in part to published reports of patient satisfaction and trials demonstrating TENS success without appropriate control groups (Augustinsson *et al*., 1977; Bundsen *et al*., 1978; Grim and Morey, 1985; Kubista, Kucena and Riss, 1978; Miller-Jones, 1980; Stewart, 1979; Vincenti, Cervellin and Mega, 1982). Augustinsson *et al*. (1976) pioneered the use of TENS in obstetrics by applying TENS to areas of the spinal cord which correspond to the input of nociceptive afferents associated with the first and second stages of labour (e.g. T10–L1 and S2–S4 respectively, Fig. 17.15). They reported that 88% of 147 women obtained pain relief using this method although the study failed to include a placebo control group (Augustinsson *et al*., 1977). Manufacturers market specially designed obstetric TENS devices which have dual channels and a 'boost' control button for contraction pain.

Two systematic reviews on TENS and labour pain concluded that evidence for TENS analgesia during labour is weak (Carroll *et al*., 1997a; Reeve, Menon and Corabian, 1996; Table 17.4). Reeve, Menon and Corabian (1996) reported that seven of nine RCTs showed no differences between TENS and sham TENS or conventional pain management (Bundsen and Ericson, 1982; Chia *et al*., 1990; Lee *et al*., 1990; Nesheim, 1981; Thomas *et al*., 1988). Carroll *et al*. (1997a) reported that five of eight RCTs showed no benefits from TENS and this was confirmed in an updated review that included two additional RCTs (Carroll *et al*., 1997b). Interestingly, Carroll *et al*. (1997b) reported that the odds ratio for trials recording additional analgesic intervention was 0.57, suggesting that analgesic intervention may be less likely with TENS, although number-needed-to-treat was high (14, 95% confidence interval 7.3–11.9). RCTs that used analgesic intake as an outcome measure would have compromised the validity of pain relief scores as patients in both sham and active TENS groups

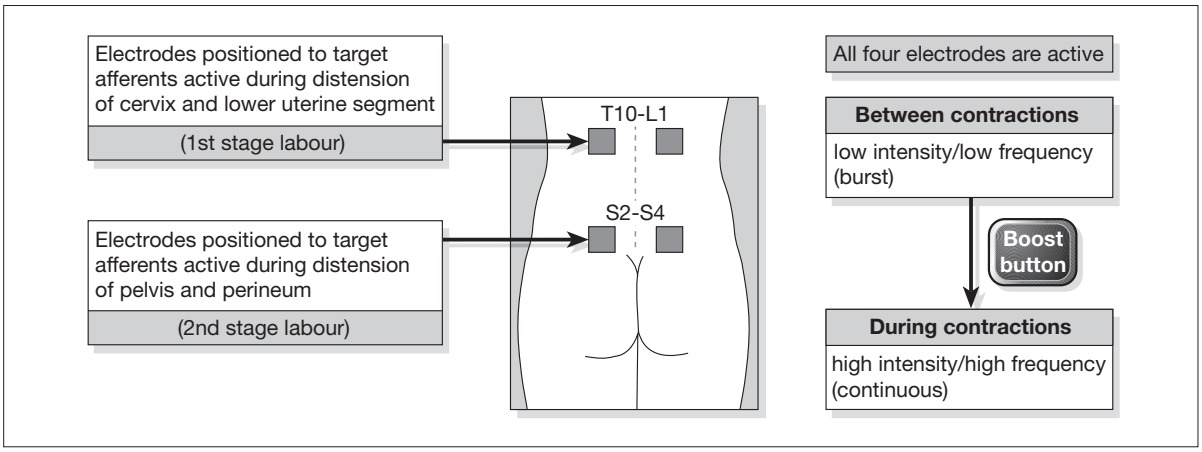

Figure 17.15 The position of electrodes and electrical characteristics of TENS when used to manage labour pain.

would consume analgesics to achieve maximal pain relief. Thus, differences in pain relief scores between TENS and sham are less likely, which will bias outcome towards no difference between groups.

In systematic reviews credence is given to trials with high methodological scores such as van der Ploeg *et al*. (1996), Harrison *et al*. (1986) and Thomas *et al*. (1988). Van der Ploeg *et al*. (1996) reported no significant differences between active and sham TENS in 94 women for additional analgesic intervention or pain relief scores. Harrison *et al*. (1986) conducted an RCT on 150 women and reported no differences between active and sham TENS users for pain relief or additional analgesic intervention. The RCT by Thomas *et al*. (1988) on 280 parturients found no significant differences between active and sham TENS for analgesic intervention or pain scores. Interestingly, under double-blind conditions women favoured active TENS when compared with sham TENS in studies by Harrison *et al*. (1986) and Thomas *et al*. (1988).

The evidence is weak for the continued use of TENS in the management of labour pain. However, this conflicts with the clinical experience of midwives and with patient satisfaction on the use of TENS (Johnson, 1997). It is possible that methodological problems associated with RCTs examining technique-based interventions may seriously bias the outcome of the systematic reviews (Bjordal and Greve, 1998). The self-report of pain relief may be unreliable when patients are experiencing fluctuating emotional and traumatic conditions as in the different stages of labour. Responses solicited at the end of childbirth, when women are relaxed and may be in a better position to judge and reflect on the effects of the intervention, may be more appropriate. Moreover, RCTs by Champagne *et al*. (1984) and Wattrisse *et al*. (1993) used transcranial TENS administered via electrodes placed on the temple. Transcranial TENS delivers electrical currents with markedly different characteristics to those of conventional obstetric TENS (Table 17.2) and it could be argued that these studies should not have been included in the review. Interestingly both of these studies demonstrated beneficial effects. Nevertheless, this raises questions about the appropriateness of the treatment protocols used in some RCTs included in the reviews. It would be unreasonable to dismiss the use of TENS for labour pain until the discrepancy between clinical experience and clinical evidence is resolved (Johnson, 2000).

TENS and chronic pain

The widespread use of TENS for chronic pain is supported by a large number of clinical trials that suggest that TENS is useful for a wide range of chronic pain conditions. Conditions include

chronic neuropathies (Thorsteinsson *et al*., 1977), postherpetic neuralgia (Nathan and Wall, 1974), trigeminal neuralgia (Bates and Nathan, 1980), phantom limb and stump pain (Finsen *et al*., 1988; Katz and Melzack, 1991; Thorsteinsson, 1987), musculoskeletal pains (Lundeberg, 1984) and arthritis (Mannheimer and Carlsson, 1979; Mannheimer, Lund and Carlsson, 1978). Myers, Woolf and Mitchell (1977) and Sloan *et al*. (1986) have shown that TENS relieves pain associated with fractured ribs.

Systematic reviews of TENS and chronic pain conclude that it is difficult to determine TENS effectiveness due to the lack of good quality trials (Flowerdew and Gadsby, 1997; Gadsby and Flowerdew, 1997; McQuay and Moore, 1998b; Reeve, Menon and Corabian, 1996). Reeve, Menon and Corabian (1996) reported that nine of 20 RCTs provided evidence that TENS was more effective than sham TENS ($n = 7$) or no treatment ($n = 2$) for a range of conditions (Table 17.4). Eight of 20 RCTs showed evidence that TENS was no more effective than sham TENS ($n = 6$) or acupuncture. It was not possible to classify the outcome of three RCTs. Reeve, Menon and Corabian (1996) concluded that the evidence was inconclusive and that the methodological quality of these trials was poor.

McQuay *et al*. (1997) also reported that there was limited evidence to assess the effectiveness of TENS in outpatient services for chronic pain. Ten of 24 RCTs provided evidence that TENS effects were better than sham TENS, placebo pills or control points such as inappropriate electrode placements (McQuay and Moore, 1998b). Fifteen RCTs compared TENS with an active treatment and only three reported that TENS provided benefit greater than the active treatment. However, over 80% of trials included in the review by McQuay and Moore (1998b) delivered TENS for less than 10 hours per week and 67% of trials delivered less than ten TENS treatment sessions. McQuay and Moore (1998b) concluded that TENS may provide some benefit in chronic pain patients if large enough (appropriate) doses are used.

Perhaps the most common use for TENS is in the management of low back pain. However, contradictory findings are found in the literature. Marchand *et al*. (1993) concluded that conventional TENS was significantly more efficient than placebo TENS in reducing pain intensity but not pain unpleasantness in 42 patients with back pain. In contrast, a RCT by Deyo *et al*. (1990b) concluded that treatment with TENS was no more effective than treatment with a placebo in 145 patients with chronic low back pain. A systematic review by Flowerdew and Gadsby (Flowerdew and Gadsby, 1997; Gadsby and Flowerdew, 1997) included only six RCTs; 62 trials were excluded as they were either non-randomised or failed to compare active TENS with a credible placebo. The meta-analysis showed that more patients improved with AL-TENS (86.70%) than with conventional TENS (45.80%) or placebo (36.40%), with greater odds ratios for AL-TENS vs. placebo (7.22) than conventional TENS vs. placebo (1.62). However, the odds ratio for AL-TENS was based on the findings of only two studies, neither of which applied AL-TENS to produce muscle contractions (Gemignani *et al*., 1991; Melzack, Vetere and Finch, 1983, see Johnson (1998) for critical review). Flowerdew and Gadsby (1997) concluded that TENS reduces pain and improves the range of movement in patients suffering chronic low back pain although a definitive RCT is still necessary in the field. Thus, at present the evidence for TENS effectiveness for chronic pain as generated from systematic reviews is inconclusive.

There is an increasing use of TENS for angina, dysmenorrhoea, pain associated with cancer and pain in children. Conventional TENS is used for angina with electrodes placed directly over the painful area of the chest (Börjesson *et al*., 1997; Mannheimer *et al*., 1982; Fig. 17.14). Mannheimer *et al.* (1985); Mannheimer, Emanuelsson and Waagstein (1990) have shown that TENS increases work capacity, decreases ST segment depression, and reduces the frequency of anginal attacks and nitroglycerin consumption when compared with control groups. A variety of types of TENS have been reported to be successful in the management of dysmenorrhea (Dawood and Ramos, 1990; Kaplan *et al*., 1994; Lewers *et al*., 1989; Milsom, Hedner and

Mannheimer, 1994; Neighbors *et al*., 1987). Most often electrodes are applied over the lower thoracic spine and sometimes on acupuncture points (Fig. 17.14, see Walsh (1997a, p. 86) for review). Success with TENS has also been reported in the palliative care setting with both adults (Avellanosa and West, 1982; Hoskin and Hanks, 1988) and children (Stevens *et al*., 1994). TENS can be used for metastatic bone disease, for pains caused by secondary deposits and for pains due to nerve compression by a neoplasm (see Thompson and Filshie (1993) for review). In these circumstances electrodes should be placed on healthy skin near to the painful area or metastatic deposit providing sensory function is preserved or alternatively the affected dermatome. TENS has been shown to be useful in the management of a variety of pains in children including dental pain (Harvey and Elliott, 1995; Oztas, Olmez and Yel, 1997; teDuits *et al*., 1993), minor procedures such as wound dressing (Merkel, Gutstein and Malviya, 1999) and venipuncture (Lander and Fowler-Kerry, 1993).

PRINCIPLES UNDERLYING APPLICATION

The basic principles of the practical application of electrical stimulation are described in Chapter 15.

Electrode positions

As conventional TENS is operating via a segmental mechanism TENS electrodes are placed to stimulate Aβ fibres which enter the same spinal segment as the nociceptive fibres associated with the origin of the pain. Thus, electrodes are applied so that currents permeate the site of pain and this is usually achieved by applying electrodes to straddle the injury or painful area (Fig. 17.14). Electrodes should always be applied to healthy innervated skin. If it is not possible to deliver currents within the site of pain, due to absence of a body part following amputation, a skin lesion or altered skin sensitivity, electrodes can be applied proximally over the main nerve trunk arising from the site of pain. Alternatively, electrodes can be applied over the spinal cord at the spinal segments related to origin of pain. Electrodes can also be applied at a site which is contralateral to the site of pain in conditions such as phantom limb pain and trigeminal neuralgia where the affected side of the face may be sensitive to touch.

Accurate placement of pads can be time consuming. Berlant (1984) has described a useful method of determining optimal electrode sites for TENS. The therapist applies one TENS electrode to the patient at a potential placement site. The second electrode is held in the hand of the therapist who uses the index finger to probe the skin of the patient to locate the best site to place the second electrode. When the TENS device is switched on and the amplitude slowly increased the patient or therapist, or both, will feel TENS paraesthesia when the circuit is made by touching the patient's skin. As the therapist probes the patient's skin with the index finger the intensity of TENS paraesthesia will increase whenever nerves on the patient's skin run superficial. This will help to target an effective electrode site.

Dual-channel devices using four electrodes or large-sized electrodes should be used for pains covering large areas. However, if the pain is generalised and widespread over a number of body parts it may be more appropriate to use AL-TENS at a relevant myotome as this may produce a more generalised analgesic effect (Johnson, 1998). Dual-channel stimulators are useful for patients with multiple pains such as low back pain and sciatica or for pains which change in their location and quality as during childbirth.

Electrical characteristics

The efficiency of different electrical characteristics of TENS to selectively activate different types of fibre was discussed earlier. For conventional TENS, selective activation of Aβ fibres is determined through the report of a strong but comfortable electrical paraesthesia without muscle contraction. Pulse frequencies anywhere between 1 and 250 p.p.s. can achieve this although clinical trials consistently report frequencies between 10 and 200 p.p.s. to be effective and popular with

patients. In practice, each patient may have an individual preference for pulse frequencies and pulse patterns and will turn to these settings on subsequent treatment sessions (Johnson, Ashton and Thompson, 1991b). As no relationship between pulse frequency and pattern used by patients and the magnitude of analgesia or their medical diagnosis has yet been found it is likely that encouraging patients to experiment with TENS settings will produce the most effective outcome (Johnson, Ashton and Thompson, 1991a).

Timing and dosage

Clinical trials report that maximum pain relief occurs when the TENS device is switched on and that analgesic effect usually disappears quickly once the device is switched off. Thus, patients using conventional TENS patients should be encouraged to use TENS whenever the pain is present. For ongoing chronic pain this may mean that patients use TENS over the entire day. In a study of long-term users of TENS Johnson, Ashton and Thompson (1991a) reported that 75% used TENS on a daily basis and 30% reported using TENS for more than 49 hours a week. When TENS is used continuously in this way it is wise to instruct the patient to monitor skin condition under the electrodes on a regular basis and take regular (although short) breaks from stimulation. It is advisable to apply electrodes to new skin on a daily basis. If TENS is administered in an outpatients clinic a dosing regimen of 20 minutes at daily, weekly or monthly intervals is likely to be ineffective.

Some patients report poststimulation analgesia although the duration of this effect varies widely, lasting anywhere between 18 hours (Augustinsson, Carlsson and Pellettieri, 1976) and 2 hours (Johnson, Ashton and Thompson, 1991a). This may reflect natural fluctuations in symptoms and the patient's expectation of treatment duration rather than specific TENS-induced effects. It is believed that post-TENS analgesia is longer for AL-TENS than for conventional TENS and this is supported by initial findings in experimental studies (Johnson, Ashton and Thompson, 1992a). However, more work is needed to establish the time course of analgesic effects of different types of TENS.

Giving a patient a trial of TENS for the first time

All new TENS patients should be given a supervised trial of TENS prior to use (Table 17.5). The purpose of the trial is to ensure TENS does not aggravate pain and to give careful instruction on equipment use and expected therapeutic outcome. Patients should be allowed to familiarise themselves on the use of TENS and therapists should use the session to check that patients can apply TENS appropriately. The initial trial can help to determine whether a patient is likely to respond to TENS and it should also be seen as an opportunity to troubleshoot problems arising

Table 17.5 Suggested characteristics to use for a patient trying TENS for the first time

	Conventional TENS	AL-TENS	Intense TENS
Electrode placement	Straddling site of pain or over main nerve bundle proximal to pain	Over muscle or motor point myotomally related to the site of pain	Straddling site of pain or over main nerve bundle proximal to pain
Pulse pattern	Continuous	Burst	Continuous
Pulse frequency	80–100 p.p.s.	80–100 p.p.s.	200 p.p.s.
Pulse duration	100–200 μs	100–200 μs	1000 μs
Pulse amplitude (intensity)	Increase intensity to produce a strong but comfortable tingling	Increase intensity to produce a strong but comfortable muscle twitch	Increase intensity to produce an uncomfortable tingling which is just bearable
Duration of stimulation in first instance	At least 30 minutes	No more than 20 minutes	No more than 5 minutes

from poor response. Ideally, the trial should last a minimum of 30–60 minutes as it may take this length of time for a patient to respond.

When using TENS on a new patient for the first time it is advisable to deliver conventional TENS as most long-term users select this type of TENS (Table 17.5). A set of audio speakers (or headphones) can be plugged into the output sockets of some TENS devices to demonstrate the sound of pulses and improve patient understanding of output characteristics of the TENS device. Following the initial trial, patients should be instructed to administer TENS in 30 minute sessions for the first few times although once they have familiarised themselves with the equipment they should be encouraged to use TENS much as they like. Patients should also be encouraged to experiment with all stimulator settings so that they achieve the most comfortable pulse frequency, pattern and duration (Table 17.6).

An early review of progress, ideally within a few weeks, can serve to ensure correct application, provide further instruction and recall TENS devices which are no longer required. Most non-responders return borrowed devices at the next clinic visit (Johnson, Ashton and Thompson, 1992b). Assessing TENS effectiveness at regular intervals is vital for tracking the location and continued use of devices. Some clinics and manufacturers allow patients to borrow TENS devices for a limited period with a view to purchasing the device. A point of contact should always be made available for patients who encounter problems.

Declining response to TENS

Some TENS users claim that the effectiveness of TENS declines over time although the exact proportion of patients is not known (see Table 92-1 in Sjölund, Eriksson and Loeser (1990) for

Table 17.6 Suggested advice following the initial trial

	Conventional TENS	AL-TENS	Intense TENS
Electrode positions	Straddle site of pain but if not successful try main nerve bundle, across spinal cord or contralateral positions—dematomal	Over muscle belly at site of pain but if not successful try motor point at site of pain, contralateral positions—myotomal	Straddle site of pain but if not successful try over main nerve bundle
Pulse pattern	Patient preference	Burst but if not successful or uncomfortable try amplitude modulated	Continuous but if not successful or uncomfortable try frequency or duration modulated
Pulse frequency	Patient preference, usually 10–200 p.p.s.	Above fusion frequency of muscle 80–100 p.p.s. within the burst	High, e.g. 200 p.p.s.
Pulse duration	Patient preference, usually 100–250 μs	Patient preference, usually 100–250 μs	Highest possible but if uncomfortable gradually reduce duration
Pulse amplitude (intensity)	Strong but comfortable sensation without visible muscle contraction	Strong but comfortable sensation with visible muscle contraction	Highest tolerable sensation with limited muscle contraction
Dosage	As much and as often as is required—have a break every hour or so	About 30 minutes at a time as fatigue may develop with ongoing muscle contractions	15 minutes at a time as the stimulation may be uncomfortable
Analgesic effects	Occur when stimulator on	Occur when stimulator on and for a while once the stimulator has been switched off May exacerbate pain	Occur when stimulator on and for a while once the stimulator has been switched off May exacerbate pain
General advice	Experiment with settings to maintain strong comfortable sensation	Experiment with settings (except burst) to maintain a phasic twitch	Experiment with settings to maintain highest tolerable sensation

summary of studies). Eriksson, Sjölund and Nielzen (1979) found that effective pain relief was achieved by 55% of chronic pain patients at 2 months, 41% at 1 year and 30% at 2 years. Loeser, Black and Christman (1975) reported that only 12% of 200 chronic pain patients obtained long-term benefits with TENS despite 68% of patients achieving initial pain relief. Woolf and Thompson (1994) suggest that the magnitude of pain relief from TENS may decline by up to 40% for many patients over a period of a year.

There may be many reasons for the decline in TENS effects with time including dead batteries, perished leads or a worsening pain problem. However, there is evidence that some patients habituate to TENS currents owing to a progressive failure of the nervous system to respond to monotonous stimuli. Pomeranz and Niznick (1987) have shown that repetitive delivery of TENS pulses at 2 p.p.s. produces habituation of late peaks (>50 ms) of SEPs. This implies that for some people the nervous system filters out monotonous stimuli associated with TENS. However, they found that delivering currents randomly to six different points on the body using a TENS-like device called a Codetron markedly reduced the habituation response (Table 17.2). Fargas-Babjak and colleagues (Fargas-Babjak, Rooney and Gerecz, 1989; Fargas-Babjak, Pomeranz and Rooney, 1992) performed a 6 week double-blind randomised placebo controlled pilot trial of the effectiveness of Codetron on osteoarthritis of the hip/knee and reported beneficial effects. Some TENS manufacturers have tried to overcome the problem of habituation by including random pulse delivery or frequency-modulated pulse delivery settings to their standard TENS devices. However, these devices have met with varied success.

If patients report that they are responding less well to TENS over time it may be worth experimenting with the electrical characteristics of TENS or with electrode placements to try and improve analgesia. It may also be worth considering temporary withdrawal of TENS treatment so that an objective assessment of the contribution of TENS to pain relief can be made. When this is done patients may report that their pain worsens in the absence of TENS, demonstrating that TENS was in fact beneficial.

HAZARDS AND CONTRAINDICATIONS

Contraindications

Contraindications to TENS are few and mostly hypothetical (Box 17.2) with few reported cases of adverse events associated with TENS in the literature. Nevertheless, therapists should be cautious when giving TENS to certain groups of patients.

- Those suffering from epilepsy (Scherder, Van Someren and Swaab, 1999): if the patient were to experience a problem while using TENS, from a legal perspective it might be difficult to exclude TENS as a potential cause of the problem.
- Women in the first trimester of pregnancy: TENS effects on fetal development are as yet unknown (although there are no reports of it being detrimental). To reduce the risk of inducing labour, TENS should not be administered over a pregnant uterus although TENS is routinely administered on the back to relieve pain during labour.
- Patients with cardiac pacemakers: this is because the electrical field generated by TENS could interfere with implanted electrical devices.

Box 17.2 Contraindications

- Undiagnosed pain (unless recommended by a medical practitioner)
- Pacemakers (unless recommended by a cardiologist)
- Heart disease (unless recommended by a cardiologist)
- Epilepsy (unless recommended by a medical practitioner)
- Pregnancy:
  - — first trimester (unless recommended by a medical practitioner)
  - — over the uterus

Do not apply TENS:
- over the carotid sinus
- on broken skin
- on dysaesthetic skin
- Internally (mouth)

Rasmussen *et al*. (1988) reported that TENS did not interfere with pacemaker performance in 51 patients although TENS may induce artifacts in monitoring equipment (Hauptman and Raza, 1992; Sliwa and Marinko, 1996). Chen *et al*. (1990) reported two cases of a Holter monitor detecting interference of a cardiac pacemaker by TENS and in both instances the sensitivity of the pacemaker was reprogrammed to resolve the problem. These authors suggest that careful evaluation and extended cardiac monitoring should be performed when using TENS with pacemakers. Therapists wishing to administer TENS to a patient with a cardiac pacemaker or any cardiac problem should always discuss the situation with a cardiologist.

- TENS should not be applied internally (mouth), or over areas of broken or damaged skin.
- Therapists should ensure that a patient has normal skin sensation prior to using TENS as if TENS is applied to skin with diminished sensation the patient may be unaware that they are administering high-intensity currents and this may result in a minor electrical skin burn.
- TENS should not be delivered over the anterior part of the neck as currents may stimulate the carotid sinus leading to an acute hypotensive response via a vasovagal reflex. TENS currents may also stimulate laryngeal nerves, leading to a laryngeal spasm.

Hazards

- Patients may experience skin irritation with TENS such as reddening beneath or around the electrodes. This is commonly due to dermatitis at the site of contact with the electrodes resulting from the constituents of electrodes, electrode gel or adhesive tape (Corazza *et al*., 1999; Fisher, 1978; Meuleman, Busschots and Dooms Goossens, 1996a, b). The development of hypoallergenic electrodes has markedly reduced the incidence of contact dermatitis. Patients should be encouraged to wash the skin (and electrodes when indicated by the manufacturer) after TENS and to apply electrodes to fresh skin on a daily basis.
- It is crucial that patients are educated on the appropriate administration of TENS. For example, patients (and therapists) should be encouraged to follow set safety procedures when applying and removing TENS (Box 17.3) to reduce the chance of an electric shock. If patients are to borrow a TENS device from a clinic they should be informed that they should not use TENS while operating vehicles or potentially hazardous equipment. In particular, drivers of motor vehicles should never use TENS while driving as a sudden surge of current may cause an accident. From a legal perspective it would be wise for TENS users to place their TENS device in a glove compartment whenever driving as the cause of an accident may be attributed to TENS if it were attached to a drivers belt (even if it was switched off). TENS can be used at bedtime providing the device has a timer so that it automatically switches off. Patients should be warned not to use TENS in

Box 17.3 Safety protocols for TENS

Protocol for the safe application of TENS
- Check contraindications with patient.
- Test skin for normal sensation using blunt/sharp test.
- TENS device should be switched off and electrode leads disconnected.
- Set electrical characteristics of TENS while device is switched off (see Tables 17.5 and 17.6).
- Connect electrodes to pins on lead wire and position electrodes on patient's skin.
- Ensure TENS device is still switched off and connect the electrode wire to the TENS device.
- Switch the TENS device ON.
- Gradually (slowly) increase the intensity until the patient experiences the first 'tingling' sensation from the stimulator.
- Gradually (slowly) increase the intensity further until the patient experiences a 'strong but comfortable' tingling sensation.
- This intensity should not be painful or cause muscle contraction (unless intense TENS or AL-TENS are being used).

Protocol for the safe termination of TENS
- Gradually (slowly) decrease the intensity until the patient experiences no tingling sensation.
- Switch the TENS device OFF.
- Disconnect the electrode wire from the TENS device.
- Disconnect electrodes from the pins on lead wire.
- Remove the electrodes from the patient's skin.

the shower or bath and keep TENS appliances out of the reach of children.

SUMMARY

TENS is used extensively in health care to manage painful conditions because it is cheap, safe and can be administered by patients themselves. Success with TENS depends on appropriate application and therefore patients and therapists need an understanding of the principles of application. When used in its conventional form TENS is delivered to selectively activate Aβ afferents leading to inhibition of nociceptive transmission in the spinal cord. It is claimed that the mechanism of action and analgesic profile of AL-TENS and intense TENS differ from conventional TENS and they may prove useful when conventional TENS is providing limited benefit. Systematic reviews of RCTs report that there is weak evidence to support the use of TENS in the management of postoperative and labour pain. However, these findings have been questioned as they contrast with clinical experience and it would be inappropriate to dismiss the use of TENS in acute pain until the reasons for the discrepancy between experience and published evidence is fully explored. Systematic reviews are more positive about the effectiveness of TENS in chronic pain. However, better-quality trials are required to determine differences in the effectiveness of different types of TENS and to compare the cost effectiveness of TENS with conventional analgesic interventions and other electrotherapies.

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