TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION (TENS)

INTRODUCTION

TENS is a method of electrical stimulation which primarily aims to provide a degree of **symptomatic pain relief** by exciting **sensory nerves** and thereby stimulating either the **pain gate mechanism** and/or the **opioid system**. The different methods of applying TENS relate to these different physiological mechanisms. The effectiveness of TENS varies with the clinical pain being treated, but research would suggest that when used 'well' it provides significantly greater pain relief than a placebo intervention. There is an extensive research base for TENS in both the clinical and laboratory settings and whilst this summary does not provide a full review of the literature, the key papers are referenced. It is worth noting that the term TENS could represent the use of ANY electrical stimulation using skin surface electrodes which has the intention of stimulating nerves. In the clinical context, it is most commonly assumed to refer to the use of electrical stimulation with the specific intention of providing symptomatic pain relief. If you do a literature search on the term TENS, do not be surprised if you come across a whole lot of 'other' types of stimulation which technically fall into this grouping.

TENS is most commonly delivered from small, hand held, battery powered devices. They can be purchased 'over the counter' in many (but not all) countries. In some locations, they need to be 'prescribed' by a therapist, doctor or other healthcare practitioner. Most multi-modal clinic based stimulators include TENS as an option, though its use in the clinic is less well supported than its use as a home based, patient delivered therapy. Examples of typical TENS units are illustrated below.

		
		
Analogue TENS devices	Digital TENS devices	Maternity TENS devices (top) and Multi modal device which includes TENS (bottom)

It is interesting that in therapy practice, the majority of practitioners consider TENS as a treatment options in circumstances when a patient is experiencing CHRONIC pain. This is not a problem as there is a significant evidence base to support this mode of application. There is however, a significant and growing body of evidence that supports the use of TENS as a valid and effective intervention in a ACUTE pain conditions.

Examples would include : Desantana et al (2009); Sbruzzi et al (2012); Silva et al (2012); Solak et al (2007) and Unterrainer et al (2010).

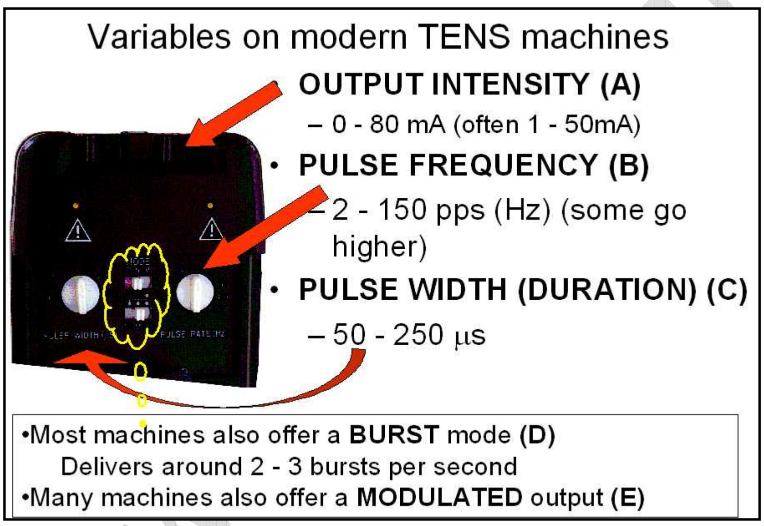
TENS as a treatment technique is **non invasive** and has few side effects when compared with drug therapy. The most common complaint is an allergic type skin reaction (about 2-3% of patients) and this is almost always due to the material of the electrodes, the conductive gel or the tape employed to hold the electrodes in place. Most TENS applications are now made using **self adhesive, pre gelled electrodes** which have several advantages including reduced cross infection risk, ease of application, lower allergy incidence rates and lower overall cost.

Garment based electrodes are becoming more widely available (examples illustrated) and for some patients provide an excellent method of application. Like the pre gelled electrodes they are supposed to be multi-use but for single patient i.e. should not be 'shared'.

Digital TENS machines are becoming more widely available and extra features (like automated frequency sweeps and more complex stimulation patterns) are emerging, though there remains little clinical evidence for enhanced efficacy at the present time. Some of these devices do offer pre-programmed and/or automated treatment settings.

MACHINE PARAMETERS:

Before attempting to describe how TENS can be employed to achieve pain relief, the main treatment variables which are available on modern machines will be outlined. The location of these controls on a typical (analogue) TENS machine is illustrated in the diagram below.



The CURRENT INTENSITY ***(A)*** (strength) will typically be in the range of 0 - 80 mA, though some machines may provide outputs up to 100mA. Although this is a small current, it is sufficient because the primary target for the therapy is the sensory nerves, and so long as sufficient current is passed through the tissues to depolarise these nerves, the modality can be effective.

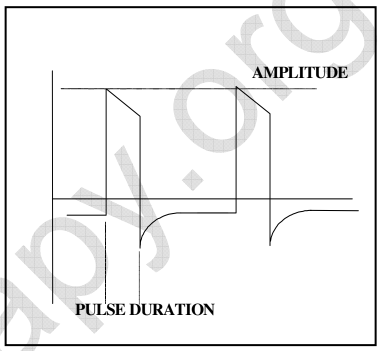
The machine will deliver discrete 'pulses' of electrical energy, and the rate of delivery of these pulses (the PULSE RATE *or* FREQUENCY ***(B)*** will normally be variable from about 1 or 2 pulses per second (pps) up to 200 or 250 pps (sometimes the term Hertz or Hz is used here). To be clinically effective, it is suggested that the TENS machine should cover a range from about 2 – 150 pps (or Hz).

In addition to the stimulation rate, the DURATION (OR WIDTH) OF EACH PULSE ***(C)*** may be varied from about 40 to 250 micro seconds (μs). (a micro second is a millionth of a second). Recent evidence would suggest that this is possibly a less important control that the intensity or the frequency and the most effective setting in the clinical environment is probably around 200μs.

The reason that such short duration pulses can be used to achieve these effects is that the targets are the sensory nerves which tend to have relatively low thresholds (i.e. they are quite easy to excite) and that they will respond to a rapid change of electrical state. There is generally no need to apply a prolonged pulse in order to force a sensory nerve to depolarise, therefore stimulation for less than a millisecond is sufficient.

In addition, most modern machines will offer a **BURST MODE** ***(D)*** in which the pulses will be allowed out in bursts or 'trains', usually at a rate of 2 - 3 bursts per second. Finally, a **MODULATION MODE** ***(E)*** may be available which employs a method of making the pulse output less regular and therefore minimising the accommodation effects which are often encountered with this type of stimulation. Both the burst and modulation modes will be discussed in more detail in the following sections.

Most machines offer a **DUAL CHANNEL OUTPUT** - i.e. two pairs of electrodes can be used simultaneously. In some circumstances this can be a distinct advantage, though it is interesting that most patients and therapists tend to use just a single channel application. Widespread and diffuse pain presentations can be usefully treated with a 4 electrode (2 channel) system, as can a combined treatment for local and referred pain (see later).



The pulses delivered by TENS stimulators vary (minimally) between manufacturers, but tend to be asymmetrical biphasic modified square wave pulses. The biphasic nature of the pulse means that there is usually no net DC component (often described in the manufacturers blurb as 'zero net DC'), thus minimising any skin reactions due to the build up of electrolytes under the electrodes.

MECHANISM OF ACTION :

The type of stimulation delivered by the TENS unit aims to **excite (stimulate) the sensory nerves**, and by so doing, **activate specific natural pain relief mechanisms**. For convenience, if one considers that there are two primary pain relief mechanisms which can be activated : the **Pain Gate Mechanism** and the **Endogenous Opioid System**, the variation in stimulation parameters used to activate these two systems will be briefly considered.

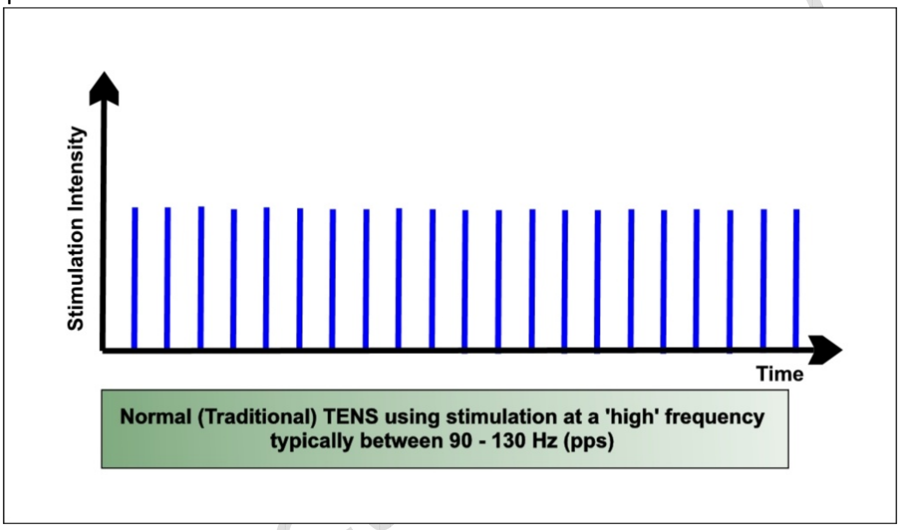
Pain relief by means of the **pain gate mechanism** involves activation (excitation) of the **A beta (Aβ) sensory fibres**, and by doing so, reduces the transmission of the noxious stimulus from the 'c' fibres, through the spinal cord and hence on to the higher centres. The Aβ fibres appear to appreciate being stimulated at a relatively high rate (in the order of **80 - 130 Hz or pps**). It is difficult to find support for the concept that there is a single frequency that works best for every patient, but this range appears to cover the majority of individuals. Clinically it is important to enable the patient to find their optimal treatment frequency – which will almost certainly vary between individuals. Setting the machine and telling the patient that this is the 'right' setting is almost certainly not going to be the maximally effective treatment, though of course, some pain relief may well be achieved.

An alternative approach is to stimulate the **A delta (Aδ) fibres** which respond preferentially to a much lower rate of stimulation (in the order of **2 - 5 Hz,** though some authors consider a wider range of 2 - 10Hz), which will activate the **opioid mechanisms**, and provide pain relief by causing the release of an endogenous opiate (encephalin) in the spinal cord which will reduce the activation of the noxious sensory pathways. In a similar way to the pain gate physiology, it is unlikely that there is a single (magic) frequency in this range that works best for everybody – patients should be encouraged to explore the options where possible.

A third possibility is to stimulate both nerve types at the same time by employing a **burst mode** stimulation. In this instance, the higher frequency stimulation output (typically at about 100Hz) is interrupted (or burst) at the rate of about 2 - 3 bursts per second. When the machine is 'on', it will deliver pulses at the 100Hz rate, thereby activating the Aβ fibres and the pain gate mechanism, but by virtue of the rate of the burst, each burst will produce excitation in the Aδ fibres, therefore stimulating the opioid mechanisms. For some patients this is by far the most effective approach to pain relief, though as a sensation, numerous patients find it less acceptable than some other forms of TENS as there is more of a ‘grabbing’, ‘clawing’ type sensation and usually more by way of muscle twitching than with the high or low frequency modes.

Traditional TENS (Hi TENS, Normal TENS)

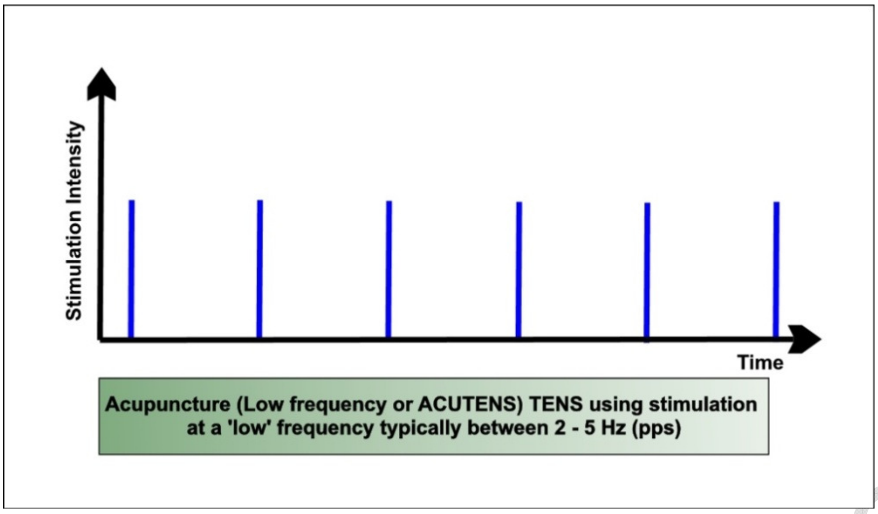
Usually uses stimulation at a relatively ***high frequency (80 - 130Hz)*** and employ a relatively narrow (short duration) pulses though as mentioned above, there is less support for manipulation of the pulse width in the current research literature. Most patients seem to find best effect at around 200µs. The stimulation is delivered at *normal intensity* this is often described (research and treatment guides) as **‘strong but comfortable’.** 30 minutes is probably the minimal effective time, but it can be delivered for as long as needed. The main pain relief is achieved during the stimulation, with a limited ‘carry over’ effect – i.e. pain relief after the machine has been switched off. Sluka et al (2013) make a very strong case relating to why (and how) TENS in this mode is most effective DURING the intervention – one should not ecpect significant post stimulation pain relief.

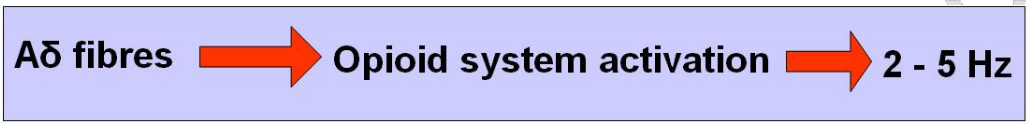


Appears to be more effective with ACUTE pains
Most effective DURING the stimulation period
Limited CARRY OVER period
Can use for as long as needed – not time limited

Acupuncture TENS (Lo TENS, AcuTENS)

Use a ***lower frequency stimulation (2-5Hz)*** with wider (longer) pulses (200-250µs). The intensity employed will usually need to be greater than with the traditional TENS - still not at the patients threshold, but quite a ***definite, strong sensation***. As previously, something like 30 minutes will need to be delivered as a minimally effective dose. It takes some time for the opioid levels to build up with this type of TENS and hence the onset of pain relief may be slower than with the traditional mode. Once sufficient opioid has been released however, it will keep on working after cessation of the stimulation. Many patients find that stimulation at this low frequency at intervals throughout the day is an effective strategy. The ‘carry over’ effect may last for several hours, though the duration of this carry over will vary between patients.





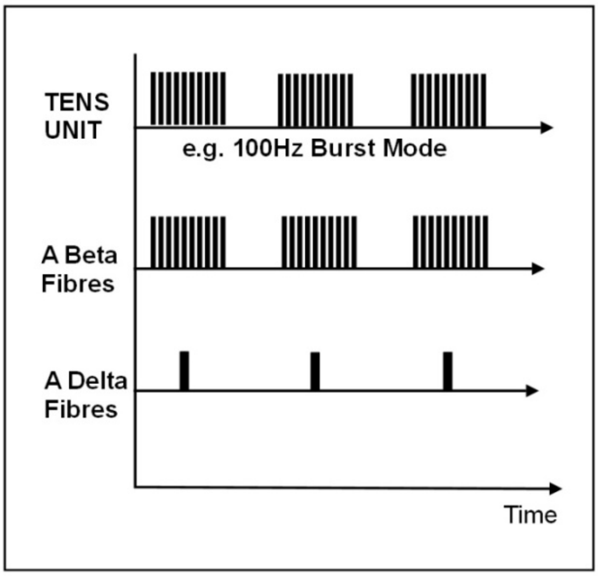
Appears to be more effective with CHRONIC pains
Effective DURING the stimulation period
But has a SIGNIFICANT CARRY OVER period
Can use for as long as needed – not time limited
Most commonly used in STIM/REST pattern
Typically 1-2 hrs ON followed by 1-2 hrs OFF

BRIEF INTENSE TENS :

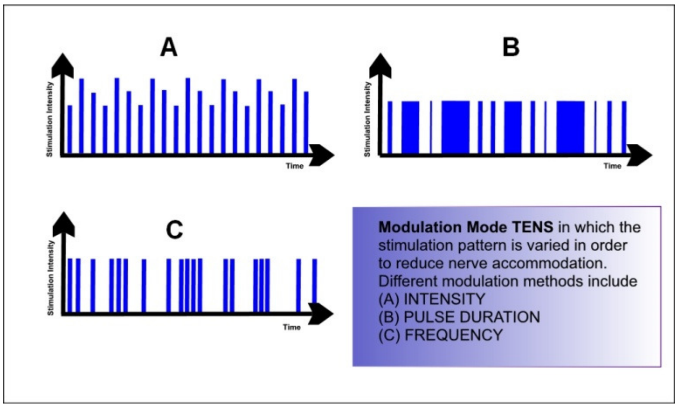
This is a TENS mode that can be employed to achieve a **rapid pain relief**, but some patients may find the strength of the stimulation too intense and will not tolerate it for sufficient duration to make the treatment worthwhile. The **pulse frequency applied is high** (in the 80-130Hz band) and the pulse duration (width) is also high (200µs plus). The current is **delivered at, or close to the tolerance level** for the patient - such that they would not want the machine turned up any higher. In this way, the energy delivery to the patients is relatively high when compared with the other approaches. It is suggested that **15 - 30 minutes** at this stimulation level is the most that would normally be used.

BURST MODE TENS :

As described above, the machine is set to deliver **traditional TENS**, but the **Burst mode** is switched in, therefore interrupting the stimulation outflow at rate of 2 - 3 bursts / second. The stimulation intensity will need to be relatively high, though not as high as the brief intense TENS – more like the Lo TENS. It is proposed that the application of **BURST mode TENS can effectively stimulate both the PAIN GATE and the OPIOID mechanisms simultaneously**.



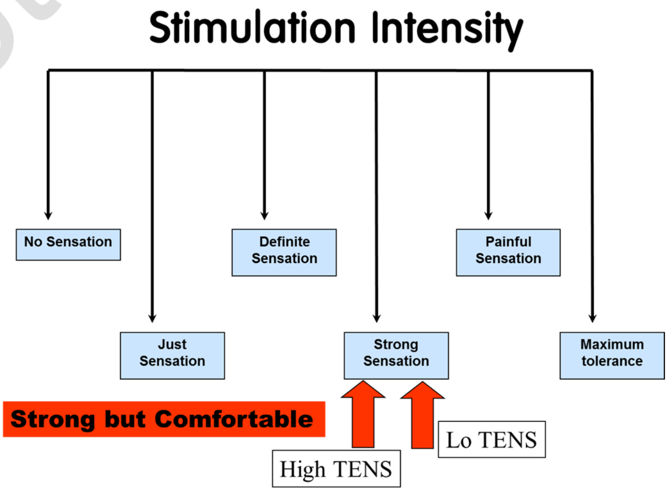
MODULATION MODE TENS



In modulation mode, the machine delivers a less regular pattern of TENS stimulation in an attempt to reduce or minimise the accommodation effects of regular, patterned stimulation. Machines offer different methods of varying the stimulation pattern – some vary the frequency, some vary the intensity and some vary the pulse duration, and some machines offer a choice between these methods, though the research evidence to date does not favour one variation method over another. This potentially most useful for patients who use TENS for hours a day, if for no other reason than accommodation occurs at a slower rate and therefore less intensity adjustment may be required.

FREQUENCY SELECTION : with all of the above mode guides, it is probably inappropriate to identify very specific frequencies that need to be applied to achieve a particular effect. If there was a single frequency that worked for everybody, it would be much easier, but the research does not support this concept. Patients (or the therapist) need to identify the most effective frequency for their pain, and manipulation of the stimulation frequency dial or button is the best way to achieve this. Patients who are told to leave the dials alone are less likely to achieve optimal effects.

STIMULATION INTENSITY : As identified above, it is not possible to describe treatment current strength in terms of how many microamps. The most effective intensity management appears to be related to **what the patient feels** during the stimulation, and this may vary from session to session. Based on recent clinical research a '**strong but comfortable**' stimulation level is probably most appropriate for both low and high frequency TENS application.



ELECTRODE PLACEMENT :

In order to get the maximal benefit from the modality, target the stimulus at the appropriate spinal cord level (appropriate to the pain). Placing the electrodes either side of the lesion – or pain areas, is the most common mechanism employed to achieve this. There are many alternatives that have been researched and found to be effective – most of which are based on the appropriate nerve root level :

- Stimulation of appropriate nerve root(s)
- Stimulate the peripheral nerve (best if proximal to the pain area)
- Stimulate motor point (innervated by the same root level)
- Stimulate trigger point(s) or acupuncture point(s)
- Stimulate the appropriate dermatome, myotome or sclerotome

If the pain source is vague, diffuse or particularly extensive, one can employ both channels simultaneously. A 2 channel application can also be effective for the management of a local + a referred pain combination –

one channel used for each component. The low frequency (Acupuncture like) TENS can be effectively applied to the contralateral side of the body.

CONTRAINDICATIONS

- Patients who do not comprehend the physiotherapist's instructions or who are unable to co-operate
- It has been widely cited that application of the electrodes over the trunk, abdomen or pelvis during pregnancy is contraindicated BUT a recent review suggests that although not an ideal (first line) treatment option, application of TENS around the trunk during pregnancy can be safely applied, and no detrimental effects have been reported in the literature (see www.electrotherapy,org for publication details)
- TENS during labour for pain relief is both safe and effective
- Patients with a Pacemaker should not be routinely treated with TENS though under carefully controlled conditions it can be safely applied. It is suggested that routine application of TENS for a patient with a pacemaker or any other implanted electronic device should be considered a contraindication.
- Patients who have an allergic response to the electrodes, gel or tape
- Electrode placement over dermatological lesions e.g. dermatitis, eczema
- Application over the anterior aspect of the neck or carotid sinus

PRECAUTIONS

- If there is abnormal skin sensation, the electrodes should preferably be positioned elsewhere to ensure effective stimulation
- Electrodes should not be placed over the eyes
- Patients who have epilepsy should be treated at the discretion of the therapist in consultation with the appropriate medical practitioner as there have been anecdotal reports of adverse outcomes, most especially (but not exclusively) associated with treatments to the neck and upper thoracic areas
- Avoid active epiphyseal regions in children (though there is no direct evidence of adverse effect)
- The use of abdominal electrodes during labour may interfere with foetal monitoring equipment and is therefore best avoided

REFERENCES – KEY TEXTS:

Johnson, M. (2014). Transcutaneous Electrical Nerve Stimulation (TENS): Research to support clinical practice, Oxford University Press.
Johnson, M. (2008). TENS In : Electrotherapy: Evidence Based Practice. Ed. Watson. T. Elsevier
Robertson, V. et al (2007). Electrotherapy Explained. Elsevier.
Walsh, D. (1997). TENS: Clinical Applications and Related Theory. Edinburgh, Churchill Livingstone.

REFERENCES – JOURNAL ARTICLES AND PAPERS:

Adedoyin, R. A., et al. (2005). "Transcutaneous electrical nerve stimulation and interferential current combined with exercise for the treatment of knee osteoarthritis: a randomised controlled trial." Hong Kong Physiotherapy Journal 23: 13-9.

Ainsworth, L., et al. (2006). "Transcutaneous electrical nerve stimulation (TENS) reduces chronic hyperalgesia induced by muscle inflammation." Pain 120(1-2): 182-7.

Alves-Guerreiro, J., et al. (2001). "The effect of three electrotherapeutic modalities upon peripheral nerve conduction and mechanical pain threshold." Clin Physiol 21(6): 704-11.

Bjordal, J. M., et al. (2007). "Short-term efficacy of physical interventions in osteoarthritic knee pain. A systematic review and meta-analysis of randomised placebo-controlled trials." BMC Musculoskelet Disord 8(1): 51.

Bodofsky, E. (2002). "Treating carpal tunnel syndrome with lasers and TENS." Arch Phys Med Rehabil 83(12): 1806; author reply 1806-7.

Brosseau, L., et al. (2003). "Transcutaneous electrical nerve stimulation (TENS) for the treatment of rheumatoid arthritis in the hand." Cochrane Database Syst Rev(3): CD004377.

Brosseau, L., et al. (2002). "Efficacy of the transcutaneous electrical nerve stimulation for the treatment of chronic low back pain." Spine 27(6): 596-603.

Brosseau, L., et al. (2004). "Efficacy of transcutaneous electrical nerve stimulation for osteoarthritis of the lower extremities: a meta-analysis." Physical Therapy Reviews 9: 213-233.

Brosseau, L., et al. (2003). "Transcutaneous electrical nerve stimulation (TENS) for the treatment of rheumatoid arthritis in the hand." Cochrane Database Syst Rev(3): CD004287.
Carroll, D., et al. (2006). "Transcutaneous electrical nerve stimulation (TENS) for chronic pain." The Cochrane Library 4(CD003222).

Chandran, P. and K. A. Sluka (2003). "Development of opioid tolerance with repeated transcutaneous electrical nerve stimulation administration." Pain 102: 195-201.

Chen, C., et al. (2008). "Does the pulse frequency of transcutaneous electrical nerve stimulation (TENS) influence hypoalgesia? A systematic review of studies using experimental pain and healthy human participants." Physiotherapy 94(1): 11-20.

Cherian, J. J. et al. (2015). "Use of Transcutaneous Electrical Nerve Stimulation Device in Early Osteoarthritis of the Knee." J Knee Surg 28(4): 321-328.

Chesterton, L. S., et al. (2002). "Sensory stimulation (TENS): effects of parameter manipulation on mechanical pain thresholds in healthy human subjects." Pain 99: 253-262.

Chesterton, L. S., et al. (2003). "Effects of TENS frequency, intensity and stimulation site parameter manipulation on pressure pain thresholds in healthy human subjects." Pain 106: 73-80.

Chiu, T. T., et al. (2005). "A randomized clinical trial of TENS and exercise for patients with chronic neck pain." Clin Rehabil 19(8): 850-60.

Claydon, L. S., et al. (2008). "Effects of simultaneous dual-site TENS stimulation on experimental pain." Eur J Pain 12(6): 696-704.

Cosmo, P., et al. (2000). "Effects of transcutaneous nerve stimulation on the microcirculation in chronic leg ulcers." Scand J Plast Reconstr Surg Hand Surg 34(1): 61-4.

Cowan, S., et al. (2009). "An investigation of the hypoalgesic effects of TENS delivered by a glove electrode." J Pain 10(7): 694-701.

de Ferrer, G. (2006). "TENS: non-invasive pain relief for the early stages of labour." British Journal of Midwifery 14(8).

Desantana, J. M. et al. (2009). "High and low frequency TENS reduce postoperative pain intensity after laparoscopic tubal ligation: a randomized controlled trial." Clin J Pain 25(1): 12-19.

Dickstein, R., et al. (2006). "TENS to the posterior aspect of the legs decreases postural sway during stance." Neurosci Lett 393(1): 51-5.

Ellis, B. (1995). "Transcutaneous electrical nerve stimulators: outpatient response to a temporary home-loan programme." Br J Therapy & Rehabilitation 2(8): 419-422.

Gadsby, J. G. and M. W. Flowerdew (2000). "Transcutaneous electrical nerve stimulation and acupuncture-like transcutaneous electrical nerve stimulation for chronic low back pain." Cochrane Database Syst Rev(2): CD000210.

Garrison, D. W. and R. D. Foreman (1994). "Decreased activity of spontaneous and noxiously evoked dorsal horn cells during transcutaneous electrical nerve stimulation (TENS)." Pain 58(3): 309-15.

Han, J. S., et al. (1991). "Effect of low- and high-frequency TENS on Met-enkephalin-Arg-Phe and dynorphin A immunoreactivity in human lumbar CSF." Pain 47(3): 295-8.

Hingne, P. M. and K. A. Sluka (2007). "Differences in waveform characteristics have no effect on the anti-hyperalgesia produced by transcutaneous electrical nerve stimulation (TENS) in rats with joint inflammation." J Pain 8(3): 251-5.

Ing, M. R. et al. (2015). "Transcutaneous electrical nerve stimulation for chronic post-herpetic neuralgia." Int J Dermatol 54(4): 476-480.

Jarzem, P. F., et al. (2005). "Transcutaneous electrical nerve stimulation [TENS] for chronic low back pain." Journal of Musculoskeletal Pain 13(2): 3-9.

Johnson, M. and M. Martinson (2007). "Efficacy of electrical nerve stimulation for chronic musculoskeletal pain: a meta-analysis of randomized controlled trials." Pain 130(1-2): 157-65.

Johnson, M. I. (2000). "The clinical effectiveness of TENS in pain management." Critical Reviews in Physical and Rehabilitation Medicine 12(2): 131-49.

Johnson, M. I. (2001). "A critical review of the analgesic effects of TENS-like devices." Physical Therapy Reviews 6(3): 153-73.

Johnson, M. I. et al. (2015). "Transcutaneous electrical nerve stimulation (TENS) for phantom pain and stump pain following amputation in adults." Cochrane Database Syst Rev 8: CD007264.

Johnson, M. (2014). "Transcutaneous electrical nerve stimulation: review of effectiveness." Nurs Stand 28(40): 44-53.

Johnson, M. I. et al. (2015). "Transcutaneous electrical nerve stimulation for acute pain." Cochrane Database Syst Rev 6: CD006142.

Khadilkar, A., et al. (2006). "Transcutaneous electrical nerve stimulation (TENS) for chronic low-back." The Cochrane Library 4(CD003008).

Khadilkar, A., et al. (2005). "Transcutaneous electrical nerve stimulation for the treatment of chronic low back pain: a systematic review." Spine 30(23): 2657-66.

Labrunee, M. et al. (2015). "Improved Walking Claudication Distance with Transcutaneous Electrical Nerve Stimulation: An Old Treatment with a New Indication in Patients with Peripheral Artery Disease." Am J Phys Med Rehabil 94(11): 941-949.

Lang, T., et al. (2007). "TENS relieves acute posttraumatic hip pain during emergency transport." J Trauma 62(1): 184-8

Lewis, M. et al. (2015). "An Economic Evaluation of TENS in Addition to Usual Primary Care Management for the Treatment of Tennis Elbow: Results from the TATE Randomized Controlled Trial." PLoS ONE 10(8): e0135460.

Loh, J. and A. Gulati (2015). "The use of transcutaneous electrical nerve stimulation (TENS) in a major cancer center for the treatment of severe cancer-related pain and associated disability." Pain Med 16(6): 1204-1210.

Lone, A. R., et al. (2003). "Analgesic efficacy of transcutaneous electrical nerve stimulation compared with diclofenac sodium in osteo-arthritis of the knee." Physiotherapy 89(8): 478-85.

Ma, D. et al. (2015). "Transcutaneous electrical acupoint stimulation for the treatment of withdrawal syndrome in heroin addicts." Pain Med 16(5): 839-848.

Miller, L., et al. (2005). "The effects of transcutaneous electrical nerve stimulation on spasticity." Physical Therapy Reviews 10(4): 201-208.

Palmer, S. T., et al. (2004). "Effects of electric stimulation on C and A delta fiber-mediated thermal perception thresholds." Arch Phys Med Rehabil 85(1): 119-28.

Perez-Ruvalcaba, I. et al. (2015). "Effect of a combined continuous and intermittent transcutaneous electrical nerve stimulation on pain perception of burn patients evaluated by visual analog scale: a pilot study." Local Reg Anesth 8: 119-122.

Robb, K. A., et al. (2007). "Transcutaneous electrical nerve stimulation vs. transcutaneous spinal electroanalgesia for chronic pain associated with breast cancer treatments." J Pain Symptom Manage 33(4): 410-9.

Robb, K., et al. (2009). "A cochrane systematic review of transcutaneous electrical nerve stimulation for cancer pain." J Pain Symptom Manage 37(4): 746-53.

Roche, P. A. and A. Wright (1990). "An investigation into the value of transcutaneous electrical nerve stimulation (TENS) for arthritic pain." Physiotherapy Theory & Practice 6: 25-33.

Rodriguez, M. A. (2005). "Transcutaneous electrical nerve stimulation during birth." British Journal of Midwifery 13(8): 522-4.

Rutjes, A. W., et al. (2009). "Transcutaneous electrostimulation for osteoarthritis of the knee." Cochrane Database Syst Rev(4): CD002823.

Santana, L. S. et al. (2016). "Transcutaneous electrical nerve stimulation (TENS) reduces pain and postpones the need for pharmacological analgesia during labour: a randomised trial." J Physiother 62(1): 29-34.

Sawant, A. et al. (2015). "Systematic review of efficacy of TENS for management of central pain in people with multiple sclerosis." Mult Scler Relat Disord 4(3): 219-227.

Sbruzzi, G. et al. (2012). "Transcutaneous electrical nerve stimulation after thoracic surgery: systematic review and meta-analysis of 11 randomized trials." Rev Bras Cir Cardiovasc 27(1): 75-87.

Searle, R. D., et al. (2009). "Transcutaneous electrical nerve stimulation (TENS) for cancer bone pain." J Pain Symptom Manage 37(3): 424-8.

Shanahan, C., et al. (2006). "Comparison of the analgesic efficacy of interferential therapy and transcutaneous electrical nerve stimulation." Physiotherapy. 92(4): 247-53.

Silva, M. et al. (2012). "Analgesic effect of transcutaneous electrical nerve stimulation after laparoscopic cholecystectomy." Am J Phys Med Rehabil 91(8): 652-657.

Sluka, K. A., et al. (2006). "Increased release of serotonin in the spinal cord during low, but not high, frequency transcutaneous electric nerve stimulation in rats with joint inflammation." Arch Phys Med Rehabil 87(8): 1137-40.

Sluka, K. A. and D. Walsh (2003). "Transcutaneous electrical nerve stimulation: basic science mechanisms and clinical effectiveness." J Pain 4(3): 109-21.

Sluka, K. et al. (2013). "What Makes Transcutaneous Electrical Nerve Stimulation Work? Making Sense of the Mixed Results in the Clinical Literature." Physical Therapy 93(10): 1397-1402.

Solak, O., et al. (2007). "Transcutaneous electric nerve stimulation for the treatment of postthoracotomy pain: a randomized prospective study." Thorac Cardiovasc Surg 55(3): 182-5.

Somers, D. L. and F. R. Clemente (2006). "Transcutaneous Electrical Nerve Stimulation for the Management of Neuropathic Pain: The Effects of Frequency and Electrode Position on Prevention of Allodynia in a Rat Model of Complex Regional Pain Syndrome Type II." Phys Ther 86(5): 698-709.

Tucker, D. L. et al. (2015). "Does transcutaneous electrical nerve stimulation (TENS) alleviate the pain experienced during bone marrow sampling in addition to standard techniques? A randomised, double-blinded, controlled trial." J Clin Pathol 68(6): 479-483.

Unterrainer, A. et al. (2010). "Postoperative and preincisional electrical nerve stimulation TENS reduce postoperative opioid requirement after major spinal surgery." J Neurosurg Anesthesiol 22(1): 1-5.

Vance, C. G., et al. (2007). "Transcutaneous electrical nerve stimulation at both high and low frequencies reduces primary hyperalgesia in rats with joint inflammation in a time-dependent manner." Phys Ther 87(1): 44-51.

Wang, K., et al. (2007). "Effect of acupuncture-like electrical stimulation on chronic tension-type headache: a randomized, double-blinded, placebo-controlled trial." Clin J Pain 23(4): 316-22.

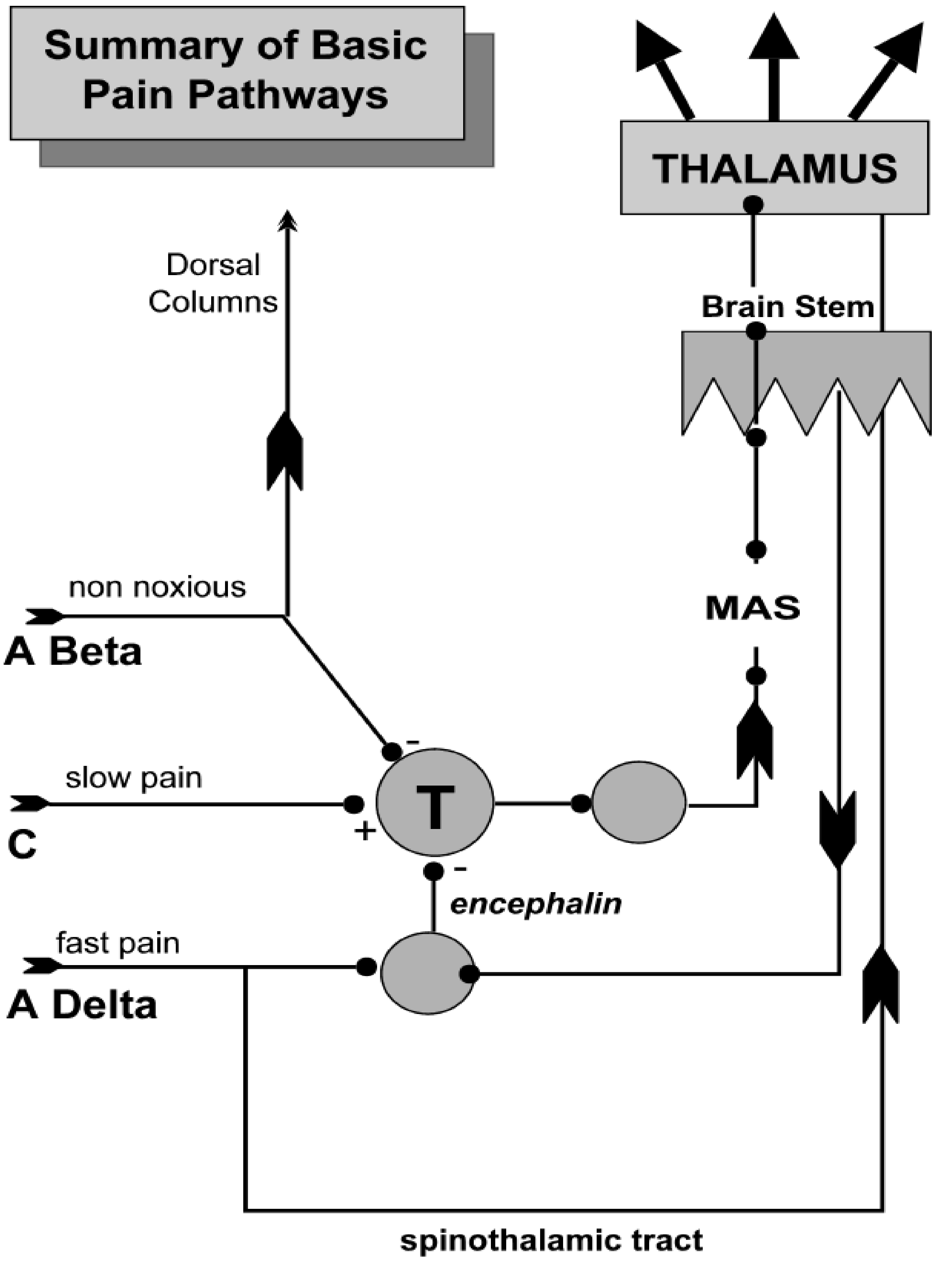
Walsh, D. M. (1996). "Transcutaneous electrical nerve stimulation and acupuncture points." Complement-Ther-Med 4: 133-137.

Walsh, D. M. and D. Baxter (1996). "Transcutaneous electrical nerve stimulation (TENS) : A review of experimental studies." Eur J Phys Med Rehabil 6(2): 42-50.

Walsh, D. M., et al. (2009). "Transcutaneous electrical nerve stimulation for acute pain." Cochrane Database Syst Rev(2): CD006142.

Ward, A. R., et al. (2009). "A comparison of the analgesic efficacy of medium-frequency alternating current and TENS." Physiotherapy 95(4): 280-8.

Yan, T. and C. W. Hui-Chan (2009). "Transcutaneous electrical stimulation on acupuncture points improves muscle function in subjects after acute stroke: a randomized controlled trial." J Rehabil Med 41(5): 312-6.


Summary of Basic Pain Pathways
THALAMUS
Dorsal Columns
Brain Stem
non noxious
A Beta
MAS
-
slow pain
T
C
+
-
encephalin
fast pain
A Delta
spinothalamic tract