The Diagnostic Value of Biometric Instruments

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Chapter 5 - The Application of Ultra-Low Frequency TENS in dentistry

Table of contents:

Abstract

TENS, as it is applied in dentistry, is not the same modality that is applied in many other disciplines of medicine. While its analgesic effects can be useful, it is the relaxation of muscles that is the primary usage. This is accomplished using a neurally-mediated, short duration pulse applied to the motor fibers of the V^{th} & VII^{th} cranial nerves. This TENS stimulation produces mild twitch contractions at less than two-times/second. Once the muscles are relaxed a bite registration can be taken short of any tooth contact that optimizes the comfort for the musculature. Secondarily, the analgesic effect of enhanced endorphin release stimulated by TENS helps indirectly to relax the muscles. The primary purpose of the application of TENS is to correct a maxillo-mandibular mal-relationship. However, to determine whether it is present or not, it is necessary to relax the muscles first. Thus, the ULF-TENS has both diagnostic and treatment applications in dentistry. Only after a maxillo-mandibular mal-relationship has been detected and described can an effective treatment begin.

The discovery of TENS

Transcutaneous Electrical Neural Stimulation (TENS) was developed most likely at least in part by accident. Ronald Melzack and Patrick Wall published their paper in 1965 describing the Gate Theory of Pain, which then led to the electrical blocking of pain signals using TENS (Melzack & Wall, 1965). The idea was to overwhelm the system with neural stimulation that would not allow the pain signals to reach the brain. The first Conventional TENS[1] units used relatively high frequencies (from 50 – 100+ pulses/second) for stimulation in an effort to exceed the capacity of the CNS to interpret incoming pain signals. This first step in the development of TENS led to a plethora of studies in the 1970s and 80s.

Nerves can be stimulated with very short duration pulses (e.g. 100 to 500 microseconds) as opposed to muscle fibers, which require a much longer (10 to 50 milliseconds) and a stronger (at least 10X) stimulus to directly depolarized muscle fibers. This means that neural stimuli can be passed through a muscle to a nerve underlying it without causing the muscle to depolarize and contract (Jankelson, Sparks, Crane & Radke, 1975; Sterkers, Renou & Hatchuel, 1975; Salar, Miotti, Rische, Antonello & Guidetti, 1983).

One of the first discoveries of the 1970s revealed the presence of endorphins (also referred to as enkephalins), the body's natural pain relievers (Mannheimer & Carlsson, 1979). These opioid-like substances are produced within the body naturally in response to pain and the body can be stimulated to release more of them. That is one of the characteristics of low frequency and burst-mode TENS. While high frequency TENS can block pain signals while the stimulus is being applied, there is little carryover after terminating the stimulus. In contrast, a low frequency TENS, by stimulating the production of endorphins, has a longer-term carryover anywhere from a few hours to days. Conventional TENS for pain relief is applied with a stimulus that is below the level that produces any muscle contraction.

Another category of TENS is for the Electrical Stimulation of Muscle contraction, with a pulse rate of 1 to 2 Hz. This type of stimulation is still neurally mediated since that requires far less energy and is infinitely more comfortable for the patient. The purpose of this type of stimulation is the relaxation of tense or fatigued muscles. Skeletal muscle needs to contract and relax. Too much of either one is not good for the health and metabolism of any skeletal muscle. Contraction pumps out the waste products of the muscle metabolism (lactic acid) through the lymph channels and relaxation allows fresh blood to bring in new metabolites.

Ultra-low frequency TENS and dentistry[2]

About the same time that Melzak and Wall were publishing on a pain suppression system, Bernard Jankelson became increasingly dissatisfied with his gnathological methods of occlusal adjustment (Jankelson, 1967). He had been applying the standard gnathological occlusal adjustments on his patients for many years but was not satisfied with the results. Some patients claimed to feel better, others did not and in some cases the chase for a satisfactory occlusion was a never-ending process, where the patient kept finding new "High Spots" ad nauseam.

A few have suggested that these types of patients are occlusal neurotics, but without offering any convincing proof or even solid objective data to support their contentions (Laskin, 1970; Greene & Laskin, 1971; Mercuri, Olson & Laskin, 1979; Schwartz, Greene & Laskin, 1979). Although a lot of opinions have been published suggesting that the etiology of temporomandibular disorders (TMD) is more mental than physical, no study has been able to successfully treat TMD with a purely psychological method. The one published effort to use cognitive behavioral therapy to treat TMD only used it in combination with conventional physical TMD treatment (Dworkin, et al, 2002).

In stark contrast, Jankelson hypothesized that to identify real occlusal interferences an involuntary closure devoid of proprioception was required. He anticipated that only this type of closure would allow the interfering tooth to strike its target without proprioceptively trying to avoid it. In 1967 he hired an unemployed Boeing engineer in Seattle to design a stimulator that could stimulate the Vth and VIIth cranial nerves simultaneously where they cross at a point just in front of the tragus of the ear deep to the mandibular notch between the condyle and the coronoid process.

The first prototype of what would become the Myo-Monitor was designed with a 2-millisecond pulse-width occurring at 1.5 second intervals. ULF-TENS is below 2 Hz. See Figure 1 below.

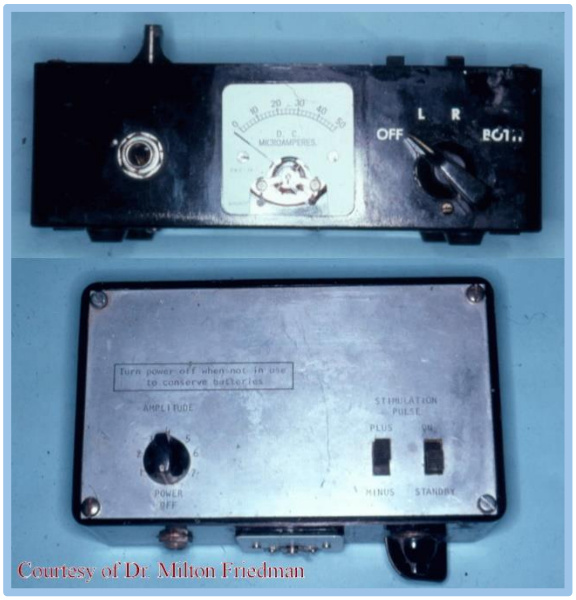

Figure 1. The first prototype of the Myo-Monitor was a very simple device emitting simultaneous left and right 2-millisecond pulses every 1.5 seconds.

The pulse-width was later shortened to 500 microseconds in the production models to reduce the sensation for the patient and to guarantee that muscle tissue could not be directly stimulated. The early models included a Burst Mode with an "Overclosure Switch" for cases where the patient was vertically over-closed and would not make any contact with just a single pulse. Eventually this feature was dropped when he realized that an over-closed patient does not need an occlusal adjustment, but restoration to a more physiologic vertical.

In the prototype the polarity of the pulses could be switched between positive and negative for the stimulating left and right electrodes with respect to the common electrode on the back of the neck. For production the polarity switch was removed and the pulse was set to always be negative on both the left and right sides. See Figures 2 & 3.

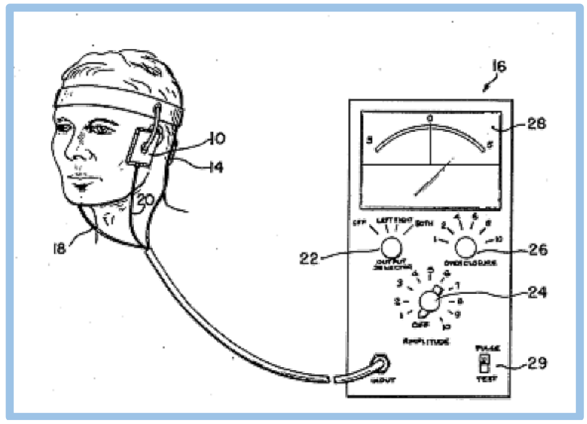

Figure 2. The first production model J2 Myo-Monitor from the patent issued in 1971. It included switches for amplitude (24), overclosure (26), test or pulse (29) and left-right-both (22).

In the mid-1970s a rash of articles were published that all claimed the Myo-Monitor could not possibly work the way it was described by Dr. Jankelson, but provided zero scientific evidence to the contrary (Bessette & Quinleven,1973; Atkinson & Shepherd, 1974; Remien, II & Ash, Jr., 1974; Noble, 1975; Azarbal, 1977; No authors listed, 1978A; No authors listed, 1978B).

Figure 3. The second production model J3 from 1977. The overclosure switch was deemed unnecessary, but the same three-lead configuration was retained.

It was repeatedly stated without evidence that the stimulation was limited to only the masseter muscles as an explanation for why the Myo-Centric position was anterior to Centric Relation.

This led to studies that demonstrated the neural mediation of the ULF-TENS stimulus (Jankelson, Sparks, Crane & Radke, 1975; McMillan, Jablonski & McMillan, 1987). However, this did nothing to satisfy some of the critics as to the application of TENS to dentistry. Forty-three years later some are still not convinced.

Meanwhile, it became apparent to Dr. Jankelson that occlusal adjustments were not as often indicated as previously thought. Many patients arriving with TMJ dysfunction syndrome, as it was then known, had many problems with their temporomandibular joints, missing teeth, painful muscles and obviously over-closed bites. Whereas previously occlusal adjustment had been the most common treatment (short of condylectomy) for all TMJ & facial pains, it became apparent that identifying only those patients that could truly benefit from an occlusal adjustment should be the first priority.

Figure 4. A mal-occlusion can require more than just an occlusal adjustment to fully correct a skeletal mal-relationship.

In spite of the negative attacks against the Myo-monitor from academia, a number of publications indicated successes using the ULF-TENS device (Dinham, 1970; Gourion, 1971; Vesanen & Vesanen, 1973; Jach, 1974; Weiss, 1974; Wessberg & Dinham, 1977; Jankelson & Radke, 1978A; Jankelson & Radke, 1978B; Rogers, 1979; Gernet, Reither & Gilde, 1980).

During the 1970s the profession was also alerted to the prevalence of disk displacement with and without reduction within the TMJ (Farrar, 1971; Weinberg, 1976; Farrar & McCarty, 1979). This led to a revival of the use of occlusal splints as a means to unload the TMJs and potentially re-capture a displaced disk. As the analysis of these patients expanded beyond just the occlusion, it became clear that a comprehensive diagnosis was needed to select the proper treatment. However, in the 1980s, some preferred to use the more invasive surgical approach of the teflon-proplast meniscal implant (Vitek, Inc., Houston, TX) to treat the TMJ internal derangements (Henry & Wolford, 1993). This device that was approved in 1989 by the FDA product panel under the paid consultation of Dr. Norman Mohl from the dental school of SUNY Buffalo, was recalled by the FDA just a few years later.

The application of ULF-TENS

The Ultra-low Frequency ULF-TENS, is applied at a level where light twitches are seen in both facial and the masticatory muscles. This level stimulates the release of endorphins, hypesthesia and produces muscle relaxation (Taylor, Katims & Ng, 1993; Frucht, Jonas & Kappert, 1995). Simultaneously, the rhythmic pulsing of the complete masticatory musculature temporarily reduces its proprioception. This is effective only as long a no tooth contacts occur. Ironically, the original intent was to produce tooth contact, but the current usage avoids that consequence.

The ideal approach for the patient with a mal-relationship and major malocclusion is to register a position short of contact with the musculature fully relaxed. This allows for the establishment of a relaxed muscle determined centric position for occlusion.

The BioTENS was developed at BioResearch Associates, Inc. in 1984 as a 2-lead bipolar wave stimulator, which does not require any common ground electrode as placed on the back of the patient’s neck. In contrast, the Myo-Monitor is a 3-lead system that uses a positive common placed on the back of the neck and that has separate monopolar negative stimulating pulses on the left and right sides. The most noticeable difference between these two devices is the greater comfort of the BioTENS as reported by patients (Gomez & Christensen, 1991).

Figure 5. The BioTENS 2-lead ULF-TENS from BioResearch, Inc. in 1984 provided a gentler and more comfortable alternative to the Myo-monitor.

The BioTENS has recently been replaced by the QuadraTENS, a two isolated channels version of BioTENS that allows the simultaneous relaxation of 4 muscle groups. The QuadraTENS includes one additional feature, a burst mode, which also enhances the production of endorphins.

The Significant Effects of ULF-TENS

The original concept of the Myo-monitor, to provide an involuntary closure that would strike any interfering occlusal contacts, is the least used function of ULF-TENS today. The stimulation of all of the masticatory muscles, producing twitch contractions and a net closing movement short of occlusal contact, provides a relaxation effect (Maffiuletti, Minetto, Farina & Bottinelli, 2011). In a recent placebo-controlled study, reductions in pain and muscle activity were found to result from ULF-TENS stimulation (Ferreira, Costa, Oliveira, et al, 2017). The pulsing simultaneously reduces the short-term proprioception of centric occlusion, the maximum intercuspal position. This process over a period of 30 to 40 minutes deprograms the CNS "muscle memory" and allows the mandible to approach a completely relaxed rest position, which is individualized and does not represent any universally consistent, predictable effect (Monaco, Cattaneo, Marci, et al, 2007). This "neuromuscular" process is most useful for the patient with a skeletal mal-relationship of the mandible to the maxilla.

Figure 6. The QuadraTENS is a 2-channel ULF-TENS doubling the capability of the BioTENS and includes a Burst Mode to enhance analgesia.

Any distortion in the skeletal relationship of the mandible to the maxilla (yaw, pitch, roll, etc.), whether developmental or traumatic, forces the musculature to adapt. Skeletal mal-relationships can be accommodated by alteration of the normal muscle contraction pattern to an awkward muscle contraction pattern (Tartaglia, Testori, Pallavera, Marelli & Sforza, 2008). For the less-adaptive patients, an awkward and unbalanced muscle contraction pattern can lead to painful symptoms in the muscles, joints and/or teeth. It has been observed that most TMD patients with painful muscle conditions have neither a myopathy nor a neuropathy. It is evidence that the muscle pains are secondary to some other primary condition, typically a biomechanical distortion.

A secondary effect of the stimulation is a longer-term analgesic effect of enhanced beta-endorphin release (also immunoreactive, Met-enkephalin-Arg-Phe and immunoreactive dynorphin A) (Hughes Jr, Lichstein, Whitlock & Harker, 1984; Han, Chen, Sun, et al, 1991; Monaco, Cattaneo, Ortu, et al, 2017). These naturally produced pain modulating opioids extend the pain suppression effect of TENS from hours to days (Patil, Iyengar, Kotni, et al, 2016). The burst mode, (high frequency bursts of 8 pulses at a less than 2 Hz repetition rate), has been determined to be especially effective at producing beta-endorphins (Mannheimer & Carlsson, 1979; Sabino, Santos, Francischi & de Resende, 2008; Rodríguez-Fernández, Garrido-Santo-fimia, Güeita-Rodríguez & Fernández-de-Las-Peñas, 2011). The suppression of pain, the elimination of proprioception and muscle relaxation are the three functions of ULF-TENS that are most useful in dentistry. The first is palliative, but the second and the third more often than not lead to corrective actions.

Using Reduced Proprioception

When a skeletal mal-relationship exists, the CNS creates a neural program to allow the muscles to function in spite of the condition. This usually results in a muscularly awkward and potentially harmful situation, where some muscles are under-loaded and others are over-loaded compared to a normal situation. E.g. Overloading the temporalis muscles can produce temporal headaches (Fernández-de-Las-Peñas, Ge, Arendt-Nielsen, Cuadrado & Pareja, 2007). In such a situation the ULF-TENS can be used to find a corrective treatment skeletal relationship that normalizes the function of the musculature. The skeletal correction can be with respect to the vertical (e.g. opening an over-closed bite), the antero-posterior (e.g. such as anterior re-positioning), correcting a lateral deflection (e.g. aligning skeletal midlines, eliminating a yaw), eliminating a high side of the occlusion (e.g. correcting a roll in the bite) or reducing premature contact either anteriorly or posteriorly (e.g. correcting a pitch). Any of these conditions are possible or even a combination of any two or more. To correct any type of mal-relationship it is only necessary; 1) to relax the musculature and 2) to take a maxillo-mandibular bite registration without any tooth contact that will deflect the closure.

Note: To understand the process of correction of a skeletal mal-relationship, it is helpful to see it happening with a jaw tracker.

Figure 7 is a highly magnified sagittal view of the mandibular movements close to the intercuspal position. The corrective position that has been selected in (the +), which is 1.2 mm above the relaxed rest position after pulsing with ULF-TENS, opens the bite just 1.8 mm at the same antero-posterior position. What is not visible in the graph is the elimination of any yaw, pitch and/or roll in the original intercuspal relationship that occurs automatically without tooth contact.

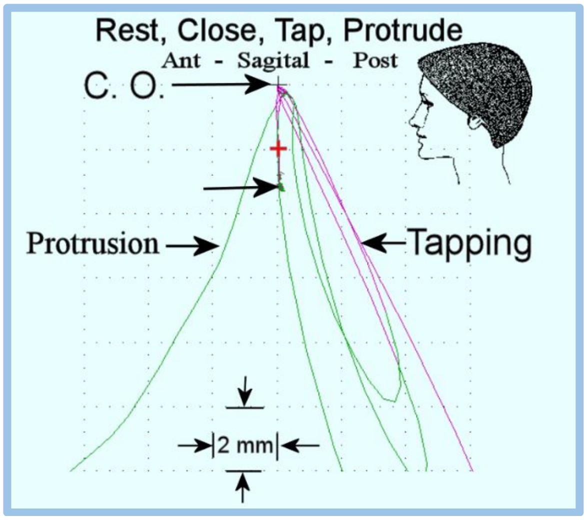

Figure 7. The target for a bite registration is shown in this graph with a + sign. This record clearly reveals the relationship of this patient's relaxed rest position to Centric Occlusion and protrusive guidance. Freeway Space in this patient is 3 mm.

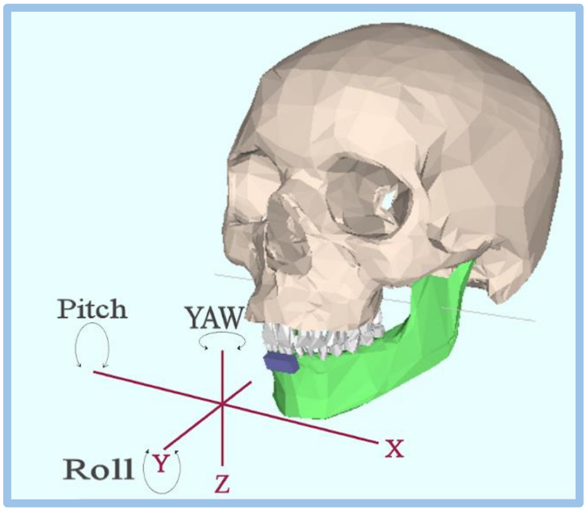

Figure 8. The relationship between the mandible and the maxilla includes the three rotations of Yaw, Pitch and Roll.

A bite registration taken at this position (the + in Figure 7.) can be used to create a full arch lower appliance with good occlusal morphology that can be used to test the patient's response. By taking the bite just short of tooth contact, proprioception does not influence the position and any yaw, pitch or roll in the original bite is removed. This procedure is referred to as the *neuromuscular bite registration* because it is

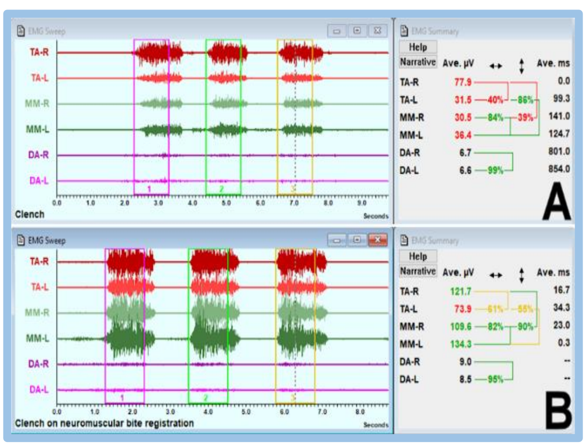

Figure 9. A maxillo-mandibular mal-relationship is the cause of the imbalanced muscle responses in (A). After a neuromuscular bite registration is obtained, a change in the muscular balance during clenching becomes quite obvious (B).

recorded with the muscles relaxed and not determined by the existing inter-relationship of the arches and the teeth that is dictated by teeth. See Figure 9.

Alternatively, if the upper arch is more distorted an upper appliance can be fabricated. In worst cases, two appliances may be needed (on the upper and lower arches) to establish a neutral maxillo-mandibular relationship.

Other Skeletal Muscles

Two other reactive muscles that may be painfully associated with TMD are the trapezius and the sternocleidomastoid. Fortuitously, the eleventh accessory nerve, although variable anatomically, is quite accessible to ULF-TENS at the posterior triangle of the neck. The trapezius' motor point is also a good stimulation point to selectively stimulate just the trapezius. These muscles can be relaxed and the endorphins that are stimulated provide additional pain relief.

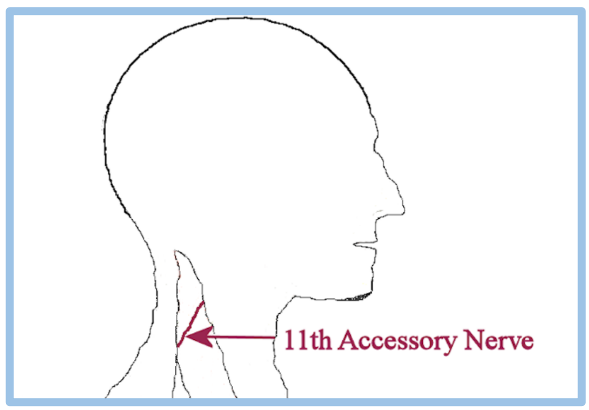

Figure 10. The 11th cranial nerve is relatively superficial crossing the posterior triangle of the neck. Placing a TENS electrode over the area allows stimulating both the trapezius and sternocleidomastoid muscles.

The posterior neck complex of muscles can also refer pain and trigger headache (Sakuta, 1995). This is due to postural requirements that increase as the head is tilted down and/or positioned forward. Forward head posture is a common clinical observation in TMD subjects along with occipital headache. In some cases malocclusion or maxillo-mandibular mal-relationship promotes forward head posture.

Skeletal muscles are consistent in character. Whether a leg muscle, arm muscle, back muscle or masticatory muscle, all skeletal muscles have a need to periodically contract and relax. While intermittent light contractions are very beneficial, forceful contractions or constant tension, even at a low level, will eventually fatigue a muscle (de Looze, Bosch & van Dieën, 2009; Pääsuke, Rannama, Ereline, Gapeyeva & Oöpik, 2007). Although there is an endpoint to the process of fatigue, myostatic contracture (or a *charlie horse* cramp), fatigue is still a gradual process. While cramping is not common in the masticatory musculature, painful muscles that are partially fatigued are very common in patients with TMD.

Significance of the Median Frequency

Muscle pain is usually associated with partial levels of fatigue that can be identified by Fast Fourier calculation of the frequency content of electromyographic (EMG) activity. Specifically, the median frequency shifts to a lower value in the presence of muscle fatigue (Merletti, Sabbahi & De Luca, 1984). There is not one median frequency that is considered normal. The range of normal precludes targeting one frequency, but within an individual measuring a change can be useful. In a partially fatigued muscle that is then relaxed into a less fatigued state, the median frequency will increase at a repeated same level of contraction. It is necessary to test the frequency at the same level of contraction because the median frequency also changes as the strength of contraction changes. Electrode location can affect the absolute value of the median frequency, but not the amount of change (Roy, De Luca & Schneider, 1986). This allows for good intra-patient comparisons as long as the electrode placement is not changed.

The muscular effects of a TENS Bite

It is possible to see the effects of a TENS bite on the musculature by recording a patient clenching in the intercuspal position and then again while clenching on an orthotic made to a neuromuscular bite registration position. See Figure 8,

When a maxillo-mandibular mal-relationship (a yaw, roll, or pitch) occurs during a closure into a clench in the intercuspal position, a very distinct imbalance in the muscle activity will be recorded by surface EMG. Some muscles will be unable to fully contract and one or more others will over-respond to make up for that. Once a more muscle-oriented position is achieved, the muscle balance in centric clenching becomes evident.

Neuropathic Pain

The general concept is that neuropathic pain is the result of systemic diseases (e.g. diabetes, spinal stenosis, etc.) or results from traumatic injury. It manifests as a sudden stabbing pain or as a chronic prickling, tingling, or burning that is felt continuously. Although strictly contradictory, it has been hypothesized by some that certain idiopathic TMD pains are neuropathic (Svensson, Baad-Hansen, Thygesen, Juhl & Jensen, 2004). Neuropathic pain may also include abnormal sensations (dysesthesia) or pain from normally non-painful stimuli (allodynia) that can have either a continuous or an episodic (paroxysmal) character.

Neuropathic pain is widely recognized in medical literature, but is associated with the accurate diagnosis of diseases or documented trauma. In contrast, references in the dental literature are more speculative and more inclined to apply neuropathic as a diagnosis to conditions with unknown etiologies (Baad-Hansen, List, Jensen & Svensson, 2006). Since TMD is a broad category of at least 40 distinct conditions, it is unlikely that neuropathic pain represents a large portion compared to the many known etiologies. Certainly, neuropathic pain can occur along with TMD, but it is not a very common co-condition and more common etiologies need to be ruled out.

Palliative Vs Corrective action

For any condition or disease of unknown etiology it is customary to apply palliative treatment. This concept has been applied to TMD in part due to the common use of the description as Myofascial Pain Dysfunction Syndrome (Laskin, 1970), or TMJ Dysfunction Syndrome, which implies an unknown etiology. The decision to use the term TMD has also promoted this idea, since with 40 different conditions included, diagnosis can seem rather overwhelming.

When the assumption is made that the etiology of TMD is unknown, a palliative approach is quite logical. However, there is evidence that there are numerous quite distinct etiologies for specific conditions that fall under the TMD category. The key to being able to apply corrective action instead of palliative therapy starts with accurate diagnosis. While not all TMD conditions can be treated with corrective action, some of them can be. The principle condition that can be corrected using ULF-TENS is a maxillo-mandibular mal-relationship.

Key Words and Definitions:

Transcutaneous Electrical Neural Stimulation (TENS): The application of microsecond long electrical pulses with surface electrodes for the stimulation of specific nerves. For dental use the most common cranial nerves stimulated are; Vth trigeminal, VIIth facial and XIth accessory. Since nerves are more sensitive to electrical stimulation the pulse durations are set too short to stimulate any nearby muscle tissue directly.

Conventional TENS: Used for acute or chronic pain suppression, it uses high frequencies (e.g. 100 Hz) at amplitudes below that which muscle contraction occurs and is applied continuously. It has little carryover after stimulation is stopped.

Low Frequency TENS: Pulse rates of 2 to 10 Hz with somewhat higher amplitudes than with conventional TENS, producing mild twitches of the associated muscles. This type of stimulation produces endorphin release and analgesia, which enhances the carryover after stimulation is ended.

Ultra-low Frequency TENS: This type of ULF-TENS stimulation pulses the nerve at 0.5 Hz to 2 Hz. It is intended to produce gentle twitch contractions of the associated musculature to stimulate blood flow, to restore a more normal metabolism and to relax the muscles. Waste products (lactic acid, etc.) are pumped out through the lymph channels while endorphins are released with analgesic effects. Carryover lasts for hours to days.

Burst Mode: Burst mode replaces a single pulse with a short train of pulses (e.g. 8) that are spaced out far enough to bridge the relaxation time. It produces a stronger, more complete contraction, more like a massage due to the treppe effect. When a series of stimuli are applied rapidly, each successive stimulus has a stronger effect than the precious one. The incrementally increasing responses are affected by increases in tissue temperature, enzyme efficiency, calcium ion availability and the structural elasticity that results from stimulation. Endorphin release is also enhanced and Burst Mode is especially effective for large muscles like the Trapezius

Accommodation: This term refers to the fact that nerves and their associated musculatures tend to adapt to the stimulation over time. When using conventional TENS, it is usually necessary to periodically re-adjust the stimulation level to maintain an ideal effect. When LF-TENS / ULF-TENS is applied, the response tends to increase over time as the muscles relax and often requires reducing the amplitude slightly.

Atypical odontalgia: A condition that is characterized by continuous pain affecting the teeth (or a tooth socket after extraction) when no identifiable cause is found after both clinical and radiographic examinations. This is another so-called TMD condition that is without a known etiologic explanation and thus, may or may not be neuropathic.

Myofascial Pain Dysfunction Syndrome: A strict definition would suggest pain originating from the fascia surrounding muscle and recognize no known etiology. This diagnosis is usually wrongfully predicated only upon the presence of painful muscles. When the etiology is unknown, only palliative treatment can be indicated.

Endorphins: Endogenous opioids released from the periaquductal gray matter of the brain by ULF-TENS stimulation that effectively modulate descending pain systems.

End Notes:

1. Conventional TENS is the term currently used to describe units that are designed only to suppress pain signals. They are also sometimes called high-frequency TENS, since the pulse rate (50 to 100 + short duration pulses/second) is the highest standard rate of all TENS units.
2. Ultra-low frequency TENS refers to units pulsing below 2 Hz and producing twitch contractions to relax muscles. They also stimulate circulation, which improves the metabolism of the muscles.

References:

Atkinson, H. F. & Shepherd, R. W. (1974). Preliminary clinical report on the Myo-Monitor. *Aust Dent J*, 19(3), 200-2. PMID: 4547963

Azarbal, M. (1977). Comparison of Myo-Monitor centric position to centric relation and centric occlusion. *J Prosthet Dent*, 38(3):331-7. PMID: 269274

Baad-Hansen L, List T, Jensen TS, Svensson P. (2006). Increased pain sensitivity to intraoral capsaicin in patients with atypical odontalgia. J Orofac Pain. 2006 Spring;20(2):107-14. PMID: 16708828

Bessette, R. W. & Quinlivan, J. T. (1973). Electro-myographic evaluation of the Myo-Monitor. *J Prosthet Dent*. 30(1),19-24. PMID: 4513524

de Looze, M., Bosch, T. & van Dieën, J. (2009). Manifestations of shoulder fatigue in prolonged activities involving low-force contractions. *Ergonomics*, 52(4), 428-37. PMID: 19401894

Dinham, R. (1970). Treatment of tic doulourex with Jankelson myo-monitor. A case report. *J Hawaii Dent Assoc*, 3(3), 11-2. PMID: 5311312

Dworkin, S. F., Turner, J. A., Mancl, L., Wilson, L., Massoth, D., Huggins, K. H., LeResche, L. & Truelove, E. (2002). A randomized clinical trial of a tailored comprehensive care treatment program for temporomandibular disorders. *J Orofac Pain*, 16(4), 259-76. PMID: 12455427

Farrar, W. B. (1971). Diagnosis and treatment of anterior dislocation of the articular disc. *N Y J Dent*, 41(10), 348-51. PMID: 5288441

Farrar, W. B. & McCarty, W. L Jr. (1979). Inferior joint space arthrography and characteristics of condylar paths in internal derangements of the TMJ. *J Prosthet Dent*, 41(5), 548-55. PMID: 286048

Fernández-de-Las-Peñas, C., Ge, H. Y., Arendt-Nielsen, L., Cuadrado, M. L. & Pareja, J. A. (2007). The local and referred pain from myofascial trigger points in the temporalis muscle contributes to pain profile in chronic tension-type headache, *Clin J Pain*, 23(9), 786-92. PMID: 18075406

Ferreira, A. P., Costa, D. R., Oliveira, A. I., Carvalho, E. A., Conti, P. C., Costa, Y. M. & Bonjardim, L. R. (2017). Short-term transcu-taneous electrical nerve stimulation reduces pain and improves the masticatory muscle activity in temporomandibular disorder patients: a randomized controlled trial. *J Appl Oral Sci*. 25(2), 112-120. PMID: 28403351

Frucht, S., Jonas, I. & Kappert, H. F. (1995). Muscle relaxation by transcutaneous electric nerve stimulation (TENS) in bruxism. An electromyographic study. *Fortschr Kieferorthop*. 56(5), 245-53. PMID: 7557797

Gernet, W., Reither, W. & Gilde, H. (1980). Use of the Myo-Monitor in the functionally disturbed stomato-gnathic system. *Dtsch Zahnarztl Z*, 35(6), 595-8. German. PMID: 6970120

Gomez, C. E. & Christensen, L, V. (1991). Stimulus-response latencies of two instruments delivering transcutaneous electrical neuromuscular stimulation (TENS). *J Oral Rehabil*, 18(1), 87-94. PMID: 2051251

Gourion, G. R. (1971). A new occlusal concept: myocentric relation and the Myo-monitor. Rev Fr Odontostomatol, 18(8), 995-1004. French. PMID: 5291294

Greene, C. S. & Laskin, D. M. (1971). Meprobamate therapy for the myofascial pain-dysfunction (MPD) syndrome: a double-blind evaluation. *J Am Dent Assoc*. 82(3), 587-90. PMID: 4924956

Han, J. S., Chen, X. H., Sun, S. L., Xu, X. J., Yuan, Y., Yan, S. C., Hao, J. Terenius, L. (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. PMID: 168608

Henry, C. H. & Wolford, L. M. (1993). Treatment outcomes for temporomandibular joint reconstruction after Proplast-Teflon implant failure. *J Oral Maxillofac Surg*. 51(4):352-8. PMID: 8450350

Hughes, G. S. Jr, Lichstein, P. R., Whitlock, D. & Harker, C. (1984). Response of plasma beta-endorphins to transcutaneous electrical nerve stimulation in healthy subjects. *Phys Ther*. 64(7), 1062-6. PMID: 6330773

Jankelson, B., Sparks, S., Crane, P. & Radke, J. (1975) Neural conduction of the Myo-Monitor Stimulus: A Quantitative Analysis, J Prosthet Dent, 30(3), 145-53. PMID: 22334985

Jach, E. T. (1974). The Jankelson Myo-Monitor. *CDS Rev*, 67(1), 20-2. PMID: 4589248

Jankelson, B. & Radke, J. C. (1978A). The Myo-monitor: its use and abuse (I). *Quintessence Int Dent Dig*, 9(2), 47-52. PMID: 275947

Jankelson, B. & Radke, J. C. (1978B). The Myo-monitor: its use and abuse (II). Quintessence Int Dent Dig, 9(3), 35-9. PMID: 287118

Laskin, D. M. (1970). Etiology of the myofascial pain-dysfunction syndrome. *J Mass Dent Soc*, 19(4), 227-8. PMID: 5277795

Maffiuletti, N. A., Minetto, M. A., Farina, D. & Bottinelli, R. (2011). Electrical stimulation for neuromuscular testing and training: State-of-the art and unresolved issues. *Eur J Appl Physiol*, 111(10), 2391–7. PMID 21866361.

Mannheimer, C. & Carlsson, C. A. (1979). The analgesic effect of transcutaneous electrical nerve stimulation (TNS) in patients with rheumatoid arthritis. A comparative study of different pulse patterns. *Pain*, 6(3), 329-34. PMID: 313550

McMillan, A. S., Jablonski, N. G. & McMillan, D. R. (1987). The position and branching pattern of the facial nerve and their effect on transcutaneous electrical stimulation in the orofacial region. *Oral Surg Oral Med Oral Pathol*, 63(5), 539-41. PMID: 3495770

Melzack, R., & Wall, P. D. (1965). Pain mechanisms: a new theory. *Science*, 150(3699), 971-9. PMID: 5320816

Mercuri, L. G., Olson, R. E. & Laskin, D. M. (1979). The specificity of response to experimental stress in patients with myofascial pain dysfunction syndrome. *J Dent Res*, 58(9), 1866-71. PMID: 290651

Merletti, R., Sabbahi, M. A. & De Luca, C. J. (1984). Median frequency of the myoelectric signal. Effects of muscle ischemia and cooling. *Eur J Appl Physiol Occup Physiol*, 52(3), 258-65. PMID: 6539676

Monaco, A., Cattaneo, R., Marci, M. C., Marzo, G., Gatto, R. & Giannoni, M. (2007). Neuromuscular diagnosis in orthodontics: effects of TENS on maxillo-mandibular relationship. *Eur J Paediatr Dent*. 8(3), 143-8. PMID: 17919063

Monaco, A., Cattaneo, R., Ortu, E., Constantinescu, M. V. & Pietropaoli, D. (2017). Sensory trigeminal ULF-TENS stimulation reduces HRV response to experimentally induced arithmetic stress: A randomized clinical trial. *Physiol Behav*. 1(173), 209-215. PMID: 28213205

No authors listed. (1978A). Comparison of Myo-Monitor centric position to centric relation and centric occlusion. *J Prosthet Dent*. 39(2), 242-4. PMID: 271738

No authors listed. (1978B). Comparison of Myo-monitor centric relation and centric occlusion. *J Prosthet Dent*, 39(4):473-4. PMID: 273698

Noble, W. H. (1975). Anteroposterior position of "Myo-Monitor centric". *J Prosthet Dent*, 33(4), 398-402. PMID: 1054417

Pääsuke, M., Rannama, L., Ereline, J., Gapeyeva, H, & Oöpik, V. (2007). Changes in soleus motoneuron pool reflex excitability and surface EMG parameters during fatiguing low- vs. high-intensity isometric contractions. *Electromyogr Clin Neurophysiol*, 47(7-8), 341-50. PMID: 18051628

Patil, S., Iyengar, A. R., Kotni, R. M, B V S. & Joshi, R. K. (2016). Evaluation of Efficacy of Ultra-sonography in the Assessment of Transcutaneous Electrical Nerve Stimulation in Subjects with Myositis and Myofascial Pain. *Korean J Pain*. 29(1), 12-7. PMID: 26839665

Remien, J. C. II, Ash, M. Jr. (1974). "Myo-Monitor centric": an evaluation. *J Prosthet Dent*, 31(2), 137-45. PMID: 4520661

Rodríguez-Fernández, A. L., Garrido-Santofimia, V., Güeita-Rodríguez, J, & Fernández-de-Las-Peñas, C. (2011). Effects of burst-type transcutaneous electrical nerve stimulation on cervical range of motion and latent myofascial trigger point pain sensitivity. *Arch Phys Med Rehabil*, 92(9), 1353-8. PMID: 21878204

Rogers, J. L. (1979). Patient's facial pain treated by Myo-monitor and dentures. *Dent Surv*, 55(5), 54. PMID: 317465

Roy, S. H., De Luca, C. J. & Schneider, J. (1986). Effects of electrode location on myoelectric conduction velocity and median frequency estimates. *J Appl Physiol*, 61(4), 1510-7. PMID: 3781964

Sabino, G. S., Santos, C. M., Francischi, J. N. & de Resende, M. A. (2008). Release of endogenous opioids following transcutaneous electric nerve stimulation in an experimental model of acute inflammatory pain. *J Pain*. 9(2), 157-63. PMID: 17988952

Sakuta, M. (1995). Tension type headache with special reference to muscle abnormality. *Rinsho Shinkeigaku*, 35(12), 1339-41. Review. Japanese. PMID: 8752391

Salar, G., Miotti, A., Rische, R., Antonello, C. & Guidetti, G. (1983). Standardized cutaneous trigeminal sensitivity. G Stomatol Ortognatodonzia. 2(4), 109-12. PMID: 6590498

Schwartz, R. A, Greene, C. S. & Laskin, D. M. (1979). Personality characteristics of patients with myofascial pain-dysfunction (MPD) syndrome unresponsive to conventional therapy. *J Dent Res*, 58(5), 1435-9. PMID: 285956

Sterkers, J. M., Renou, G. & Hatchuel, C. (1975). The facial nerve sensitivity test. Significance and limitation. Ann Otolaryngol Chir Cervicofac. 92(4-5), 173-7. PMID: 1217811

Svensson P, Baad-Hansen L, Thygesen T, Juhl GI, Jensen TS. (2004). Overview on tools and methods to assess neuropathic trigeminal pain. J Orofac Pain. 2004 Fall;18(4):332-8. PMID: 15636017

Tartaglia, G. M., Testori, T., Pallavera, A., Marelli, B. & Sforza, C. (2008). Electromyographic analysis of masticatory and neck muscles in subjects with natural dentition, teeth-supported and implant-supported prostheses. *Clin Oral Implants Res*, 19(10), 1081-8. PMID: 18828826

Taylor, D. N., Katims, J. J. & Ng, L, K. (1993). Sine-wave auricular TENS produces frequency-dependent hypesthesia in the trigeminal nerve. Clin J Pain. 9(3), 216-9. PMID: 8219523

Vesanen, E. & Vesanen, R. (1973). The Jankelson Myo-Monitor and its clinical use. *Proc Finn Dent Soc*, 69(6), 244-7. PMID: 4591388

Weinberg, L. A. (1976). Posterior bilateral condylar displacement: its diagnosis and treatment. *J Prosthet Dent*, 36(4), 426-40. PMID: 1067424

Weiss, M. H. (1974). Letter: Myo-Monitor centric. *J Prosthet Dent*, 31(6), 695-6. PMID: 4524864

Wessberg, G. A. & Dinham, R. (1977). The Myo-Monitor and the Myofacial Pain Dysfunction Syndrome. *J Hawaii Dent Assoc*, 10(2), 10-3. PMID: 346640

Additional Readings

Cekmen, N., Salman, B., Keles, Z., Aslan, M. & Akcabay, M. (Feb 2007). "Transcutaneous electrical nerve stimulation in the prevention of postoperative nausea and vomiting after elective laparoscopic cholecystectomy". *J Clin Anesth*. 19 (1), 49–52. PMID 17321927

Gan, L. S., Prochazka, A., Bornes, T. D., Denington, A. A. & Chan, K. M. (2007). "A new means of transcutaneous coupling for neural prostheses". *IEEE Trans Biomed Eng*. 54 (3), 509–17. PMID 17355064

Ozawa, M., Tsuchiyama, K., Gomi, R., Kurosaki, F., Kawamoto, Y. & Aiba, S. (2006). "Neuroselective transcutaneous electric stimulation reveals body area-specific differences in itch perception". *American Academy of Dermatology*. 55 (6), 996–1002. PMID 17097397

Vrbová, G., Hudlicka, O. & Schaefer-Centofanti, K. (2008). Application of Muscle/Nerve Stimulation in Health and Disease. Springer. ISBN 978-1-4020-8232-0.

Robinson-Andrew, J. & Snyder-Mackler, L. (2007). Clinical Electrophysiology: Electrotherapy and Electrophysiologic Testing (Third ed.). Lippincott Williams & Wilkins. ISBN 0781744849.

DeSantana, J. M., Walsh, D. M., Vance, C., Rakel, B. A. & Sluka, K. A. (2008). "Effectiveness of Transcutaneous Electrical Nerve Stimulation for Treatment of Hyperalgesia and Pain". *Curr Rheumatol Rep*. 10(6), 492–499. PMID 19007541

Johnson, M. & Martinson, M. (2007). "Efficacy of electrical nerve stimulation for chronic musculoskeletal pain: A meta-analysis of randomized controlled trials". *Pain*. 130(1–2), 157–165. PMID 17383095

Nnoaham, K. E. & Kumbang, J. (2008). Nnoaham, Kelechi E, ed. "Transcutaneous electrical nerve stimulation (TENS) for chronic pain". *The Cochrane Library* (3): CD003222. PMID 18646088

Haldeman, S., Carroll, L., Cassidy, J. D., Schubert, J. & Nygren, A. (2008). "The Bone and Joint Decade 2000–2010 Task Force on Neck Pain and Its Associated Disorders." *Spine*. 33(4 Suppl), S5–S7. PMID 18204400

Dubinsky, R. M. & Miyasaki, J. (2009). "Assessment: Efficacy of transcutaneous electric nerve stimulation in the treatment of pain in neurologic disorders (an evidence-based review): Report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology". *Neurology*. 74(2), 173–176. PMID 20042705

Khadilkar, A., Odebiyi, D. O., Brosseau, L. & Wells, G. A. (2008). Brosseau, Lucie, ed. "Transcutaneous electrical nerve stimulation (TENS) versus placebo for chronic low-back pain". *The Cochrane Library* (4), CD003008. PMID 18843638

Johnson, M. I., Mulvey, M. R. & Bagnall, A. M. (2015). "Transcutaneous electrical nerve stimulation (TENS) for phantom pain and stump pain following amputation in adults". *Cochrane Database of Systematic Reviews*. 8, CD007264. PMID 26284511

Bjordal, J. M., Johnson, M. I. & Ljunggreen, A. E. (2003). "Transcutaneous electrical nerve stimulation (TENS) can reduce postoperative analgesic consumption. A meta-analysis with assessment of optimal treatment parameters for postoperative pain". *European Journal of Pain*. 7(2), 181–188. PMID 12600800

Rakel, B. & Frantz, R. (2003). "Effectiveness of transcutaneous electrical nerve stimulation on postoperative pain with movement". *The Journal of Pain*. 4(8), 455–464. PMID 14622666

Bennett, M. I., Hughes, N. & Johnson, M. I. (2011). "Methodological quality in randomised controlled trials of transcutaneous electric nerve stimulation for pain: Low fidelity may explain negative findings". *Pain*. 152(6), 1226–1232. PMID 21435786

Ellrich, J. & Lamp, S. (2005). "Peripheral Nerve Stimulation Inhibits Nociceptive Processing: An Electrophysiological Study in Healthy Volunteers." *Neuromodulation: Technology at the Neural Interface*. 8(4), 225–232. PMID 22151549

Kara, M., Ozçakar, L., Gökçay, D., Ozçelik, E., Yörübulut, M., Güneri, S., Kaymak, B., Akinci, A. & Cetin, A. (2010). "Quantification of the Effects of Transcutaneous Electrical Nerve Stimulation with Functional Magnetic Resonance Imaging: A Double-Blind Randomized Placebo-Controlled Study". *Archives of Physical Medicine and Rehabilitation*. 91(8), 1160–1165. PMID 20684895

Kocyigit, F., Akalin, E., Gezer, N. S., Orbay, O., Kocyigit, A. & Ada, E. (2012). "Functional Magnetic Resonance Imaging of the Effects of Low-frequency Transcutaneous Electrical Nerve Stimulation on Central Pain Modulation". *The Clinical Journal of Pain*. 28(7), 581–588. PMID 22699130

Schoenen, J., Vandersmissen, B., Jeangette, S., Herroelen, L., Vandenheede, M., Gérard, P. & Magis, D. (2013). "Migraine prevention with a supraorbital transcutaneous stimulator: a randomized controlled trial". *Neurology*. 80(8), 697–704. PMID 23390177

McQuay, H. J., Moore, R. A., Eccleston, C., Morley, S. & Williams, A. C. (1997). "Systematic review of outpatient services for chronic pain control". *Health Technology Assessment*. 1(6), i–iv, 1–135. PMID 9483161

van der Spank, J. T., Cambier, D. C., De Paepe, H. M., Danneels, L. A., Witvrouw, E. E. & Beerens, L. (2000). "Pain relief in labour by transcutaneous electrical nerve stimulation (TENS)". *Archives of gynecology and obstetrics*. 264(3), 131–136. PMID 11129512

Chipaila, N., Sgolastra, F., Spadaro, A., Pietropaoli, D., Masci, C., Cattaneo, R, & Monaco, A. (2014). "The effects of ULF-TENS stimulation on gnathology: the state of the art". *Cranio: The Journal of Craniomandibular Practice*. 32(2), 118–130. PMID 24839723

Jensen, J. E., Conn, R. R., Hazelrigg, G. & Hewett, J. E. (1985). "The use of transcutaneous neural stimulation and isokinetic testing in arthroscopic knee surgery". *The American journal of sports medicine.* 13(1), 27–33. PMID 3872082

Burton, C. (1974). "Instrumentation for dorsal column stimulator implantation". *Surgical neurology*. 2(1), 39–40. PMID 4810453

Monaco, A., Cattaneo, R., Ortu, E., Constantinescu, M. V. & Pietropaoli, D. (2017). "Sensory trigeminal ULF-TENS stimulation reduces HRV response to experimentally induced arithmetic stress: A randomized clinical trial". *Physiology & Behavior*. 173, 209–215. ISSN 1873-507X. PMID 28213205

Bracciano, A. G. (2008). Physical Agent Modalities: Theory and Application for the Occupational Therapist (2 ed.). SLACK Incorporated. p. 232. ISBN 1556426496.

Digby, G. C., Daubney, M. E., Baggs, J., Campbell, D., Simpson, C. S., Redfearn, D. P., Brennan, F. J., Abdollah, H. & Baranchuk, A. (2009). "Physiotherapy and cardiac rhythm devices: a review of the current scope of practice". *Europace*. 11(7), 850 - 59. PMID 19411677

Appendix to Chapter 5

In the dental application of TENS, the stimulating electrode is usually placed directly anterior to the tragus of the ear, over the coronoid notch of the mandible. This location fortuitously gives access to both the V^{th} and the VII^{th} cranial nerves.

See Figure 1.

Figure 1. The most common placement of the TENS electrode for dental applications is bilaterally anterior to the tragus and over the coronoid notch. Using a bipolar stimulus, no “ground” or reference electrode is required. Unipolar systems require a ground, usually placed on the back of the neck.

Since the facial nerve is closer to the dermis, it responds at a lower amplitude than the trigeminal nerve. Thus, the process of setting the amplitude can occur in three steps.

1. The amplitude can be slowly increased until the patient can sense a pin-prick at the level of the dermis. This indicate the stimulus is reaching only the pain sensors within the dermis.
2. As the amplitude is slowly increased the indication that the motor fibers of the VII^{th} cranial nerve are being stimulated is observed with a discernable twitching of the facial muscles around the eyes and nose.
3. Finally, continuing to slowly increase the amplitude, the masseters may be palpated or a finger may be placed between the incisal edges of the teeth to detect a slight twitch contraction of the masticatory muscles. This level of contraction is referred to as the “threshold” and is acceptable for muscle relaxation. There is no definite limit to the amount of time that the stimulus can be applied, but forty minutes to one hour provide a maximal effect and longer applications do not add to significantly.

Ideally, the patient should be in a comfortable chair, a quiet space and not involved in any activity. The head may be tipped back on a rest, but not forward, which could cause the teeth to impact. Instruct the patient to avoid tooth contact or to let you know if it occurs.

You can reassure the patient that the initial “pin prick” sensation will go away within a few moments as the endorphins are released. In the case of extreme anterior misguidance (e.g. Class II div 2) it is recommended to use an Aqualizer™ to cover the maxillary teeth and to keep the teeth from contacting while pulsing.

The state of relaxation and temporary lack of proprioception that is induced by the TENS is quite fleeting if the patient is immediately allowed to close into centric occlusion. Thus, any bite registration (when indicated) should be taken before that occurs if possible. If done immediately, a registration can correct any yaw, pitch or roll that is present in the maximum intercuspal position.