

The effects of ULF–TENS stimulation on gnathology: the state of the art

Nicolae Chipaila, Fabrizio Sgolastra, Alessandro Spadaro, Davide Pietropaoli, Chiara Masci, Ruggero Cattaneo, Annalisa Monaco

Department of Life, Health and Environmental Sciences, Unit of Gnathology, University of L'Aquila, L'Aquila, Italy

Aims: The aim of this study was to evaluate the state of the art in the current literature regarding the effect of ultra low frequency–transcutaneous electrical nerve stimulation (ULF–TENS) on patients with temporomandibular disorders (TMD).

Methodology: The authors reviewed the literature through a thorough manual and electronic research on PubMed database (using the Medical Subject Headings thesaurus) and subsequent analysis of all the found papers regarding the effect of TENS on TMD patients. No randomized controlled trials on the investigated topic were found. Only eight papers regarding controlled clinical trials (CCT) were selected according to the search strategy selection criteria.

Results: According to the available literature and the authors' experience, ULF–TENS seems to be a valid support in the management of TMD patients, but also a 'provocative' tool, so its application should always be monitored by electromyographic and electrognathographic analysis (before and after TENS).

Conclusions: Further clinical studies (mainly randomized controlled trials) on ULF–TENS application in neuromuscular gnathology are needed.

Keywords: TENS, TMD patients, Masticatory muscles

Introduction

Temporomandibular disorders (TMD): definition and characteristics

TMD comprise a group of musculoskeletal disorders, affecting alterations in the structure and/or function of the temporomandibular joints, masticatory muscles, dentition, and supporting structures.¹

Currently, two classification systems are adopted as the reference standard, both for clinical practice and the design of scientific studies. Both systems have a marked clinical guidance, and are based mainly on symptoms such as pain in the preauricular area and/or in the masticatory muscles system, abnormalities in mandibular movements, and joint sounds, such as clicks and/or crackles during the excursions. The diagnostic reference classifications are: (1) the one established by the American Academy of Orofacial Pain² in collaboration with the International Headache Society, and (2) the one that is represented by the

Research Diagnostic Criteria for Temporomandibular Disorders.³

The latter is the classification system used by most researchers, and frames the TMD from a dual point of view, clinical and psychosocial, and refers to the least operator dependent investigation criteria, and therefore, is based on standardized objectification criteria.^{3–5}

According to the most recent literature reviews, the prevalence of TMD in the general population reported by several authors varies between 12 and 60%, and the data from different studies are therefore very much influenced by the sampling methodology and diagnostic criteria adopted.^{6,7} The most affected are women between 25 and 45 years old, with a prevalence more than double that of men.

The etiology and pathogenesis of TMD are still poorly understood.⁸ However, in the pathogenic sequence of masticatory system disorders, it is possible to identify the presence of an event able to alter the threshold of individual physiological tolerance, and to induce the onset of symptoms. The 'physiologic tolerance' represents the limit of individual adaptability to a certain degree of functional interference.

Correspondence to: Dr Nicolae Chipaila, University of L'Aquila, Department of Life, Health and Environmental Sciences, Unit of Gnathology, Via Vetoio 1, 67100, L'Aquila, Italy. Email: nicolae.chipaila@libero.it

However, this parameter cannot be investigated scientifically, since it is extremely modulated by different factors. These events may be local (e.g. change in proprioceptive input after trauma or parafunction and central excitatory effect of deep pain) or systemic (represented mainly by stress).⁶

Currently, the scientific community agrees to bring the development of TMD to a multifactorial etiology, which combine several factors, including the main ones: psychological, occlusal, parafunctional, traumatic, hormonal, postural, neuromuscular.⁹⁻¹⁵

The diagnosis of TMD is generally based on clinical examination of the patient; however, there are other diagnostic tools, such as surface electromyography (sEMG) and computerized electrognathography, which provide substantial information about the muscle activity and jaw movements' dynamics on the stomatognathic system unit.

The pain reduction and the normal jaw function restoration are the main goals of conservative management of TMD.¹⁶

Some of the conservative therapies proposed for the treatment of TMD are: physical therapy, cognitive-behavioral techniques, drug therapy, occlusal splints, occlusal arrangement, acupuncture, low level laser therapy (LLL), and transcutaneous electrical nerve stimulation (TENS).^{1,17-22}

The aim of this work is to evaluate the state of the art regarding the effects of TENS on TMD patients.

TENS: definition

TENS is a technique that involves the application of an electrical stimulus on the major nerves. In relation to the parameters used (amplitude and impulse duration), it is possible to act on the major nerves through a targeted neurophysiological mechanism.

How to use the term 'TENS'

Generally, when we use the term 'TENS' in rehabilitative medicine we refer to antalgic TENS (pain suppressing TENS). In dentistry, we use the term 'TENS' framing it as a neuromuscular TENS (functional muscle stimulation). The characteristics of each of the two stimulations will be described below.

Antalgic TENS

In general medicine, TENS is a therapeutic modality, mainly used for the treatment of musculoskeletal pain, as it promotes analgesic effects.

The idea of using a source of electrical stimulation as a therapy in reducing the allergic phenomena is not a recent concept in the world of medicine. In fact, as Katch²³ stated in his work of 1986, as early as 46 AD Scribonius Largus, the court physician of the Roman

emperor Claudius proposed the use of electric eels in the treatment of headaches and gout.

Two types of TENS are used clinically, low frequency TENS (frequency of stimulation <10 Hz, LF) and high frequency TENS (frequency of stimulation >50 Hz, HF). In clinical and research practice, frequencies <5 Hz for the low frequency and >100 Hz for the high frequency are employed.

It must be pointed out that within the frequency, electrostimulation classification under 1000 Hz is considered low frequency. Thus, both the 'low' and 'high' frequency of stimulation for analgesic use are subclasses of the more general low-frequency stimulation. Hence the term ultra low frequency (ULF) attributed to stimulation with TENS frequency less than 4 Hz.

The distinction in the field of antalgic TENS between low and high frequency has followed a physiopathogenetic principle. It was believed that the mechanism of action of LF and HF TENS on the pain was quite different.²⁴ From the clinical finding, which is not always detectable, it was found that the TENS effect is obtainable with different stimulation modalities.^{25,26}

The LF-TENS analgesia, obtained with 20-45 minutes administration times, was longer lasting after the suspension of the pulse, while the HF-TENS analgesia was rapid in setting up but quickly stopped once stimulation was suspended.²⁴⁻²⁶

LF-TENS stimulation, to be able to evoke the movement of the joint segment, must be administered to such an amplitude as to feel uncomfortable by the subject who receives it. Therefore, the low frequency stimulation would be conducted on the small caliber sensory fibers, which carry the pain and deep sensibility.²⁴⁻²⁶ Once in the posterior horn of the medulla, the second order activated neuron would project at the level of various areas of the trunk, including the periaqueductal gray and other areas throughout defined Substance Producing Analgesia coding for an endorphin analgesic effect.^{27,28} The endorphin path needs a longer time to be activated, but is active for longer, as long as the endorphins have been degraded and have ceased their activity.

HF-TENS is not felt by the subject, except as a slight tingling sensation. The feeling is not unpleasant; indeed, it is sometimes perceived as pleasant.

It is assumed that the stimulation, which does not cause pain, is conducted along sensory fibers of large caliber. The second order medullary neuron would be controlled by an inhibitor interneuron. The activation of this interneuron inhibits the transmission of the second order neuron, while its inhibition would



Figure 1 Conventional TENS stimulator device.

lead to a greater freedom of transmission of the second order neuron. The HF-TENS would act on this interneuron. In fact, the large caliber fibers would send an excitatory collateral to the inhibitor interneuron, which, once activated, would lead to the transmission inhibition by the spinal cord second order neuron. Any information on this second-order neuron should come from the periphery, for example, conveyed by nociceptive fibers, and would be blocked because the second-order neuron was inhibited by the interneuron excited by pulses (HF-TENS) running on the fibers of large caliber: the gate closes.

The phenomenon would be 'direct' and the feedback could be active only in the presence of stimulation of large nerve fibers. The analgesic effect would cease at the time of HF-TENS cessation.

Generally, high frequency and low intensity characteristics of stimulation are those that allow us to call this kind of application 'conventional' (Fig. 1).

Conventional TENS works via Melzack and Wall's 'gate control' theory,²⁹ by the activation of peripheral inhibition systems of nociceptive stimuli, and by stimulating production and release of endogenous opioids, neuropeptides and neurotransmitters with

analgesic action. Neither action mechanism would have a simple symptomatic action, but would act with synergy and graduality, obtaining a sort of 'reset' of the nociceptive system. Other action mechanisms, such as the metabolic recovery of the muscular tissue and the unloading reflex, hypnosis and stress analgesia, exteroceptive suppression and counter irritation, endogenous inhibition and sympathetic activity reduction have also been suggested by Galletti *et al.*³⁰

Neuromuscular TENS

Regarding the purely muscular component, it has been argued that the impulse is conducted by dromic and antidromic methods. The dromic method would mean that, once it meets the motor nerve trunk, the current is conveyed to the periphery in order to achieve the innervated muscle fibers. The effect of this path would lead to contraction of the muscle itself and, if the stimulus amplitude is sufficient to determine the activation of a sufficient number of motor units and if the muscle ancillary articular heads are free, there may be a shift of the body segment. Specifically, a contraction of the lip, the eyelid or the raising of the jaw by the action of the VIIth or the Vth pair of cranial nerves could occur.

The effect due to the muscle contraction implies, then, a series of side effects related to the activation of the reflexes circuits mediated by neuromuscular spindles, by the stretching of the tendons, which in turn contribute to modulate the effects of the second, third or hundredth pulse generated by TENS.

Often these aspects are neglected in the explanation of the TENS effect. This may be a mistake, because even at this level, one should recognize the considerable complexity of action and central connection that should not be overlooked in considering the effects, even purely muscular of transcutaneous electrical nerve stimulation.

The second path covered by the impulse is defined antidromic. In short, the impulse besides being conducted towards the muscular periphery, would be conducted to the motor nuclei of the involved nerves. This would bring the direct activation of motor neurons and, through them, the impulse would then be carried to the muscles.

Neuromuscular TENS or ULF-TENS was proposed for the first time by Jankelson³¹ in 1969, and is currently studied and has been used as a TMD therapeutic strategy by several authors.^{22,32,33} It consists in the application of three electrodes, two active electrodes (anode), positioned on the skin overlying the sigmoid notch of the jaw, immediately

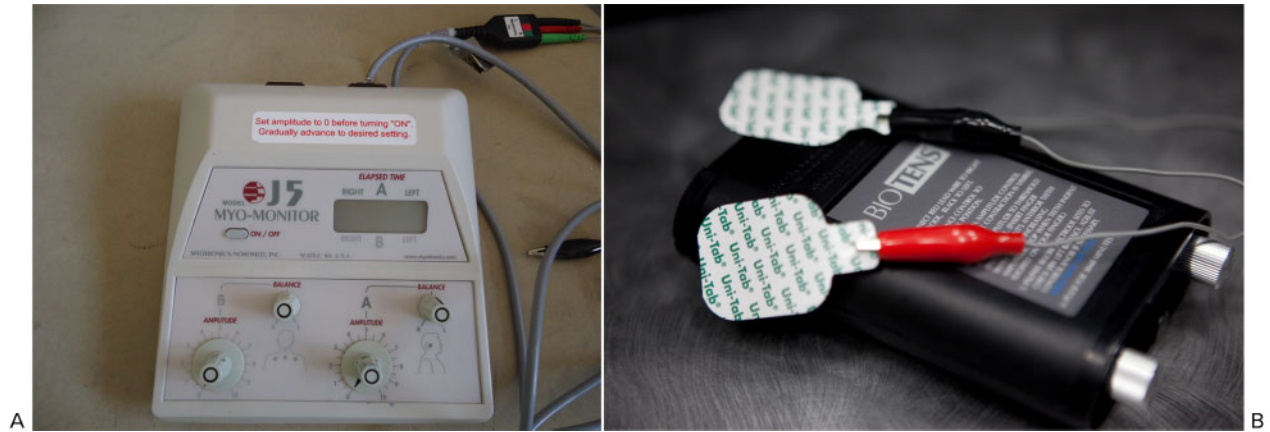


Figure 2 (A) Neuromuscular TENS stimulator device. (B) Neuromuscular TENS stimulator device.

before the tragus, and the third reference (cathode) on the midline neck immediately below the hair line (Figs. 2A–6).³⁴

The current used is pulsed with a frequency of 0.66 Hz, and each pulse has a duration of 500 microseconds and an amplitude of 8–12 mA. TENS applied to the sigmoid notch allows the excitation of motor nerve fibers of the Vth pair of cranial nerves,

resulting in relaxation of the masticatory musculature (Figs. 7–15). It also allows the achievement of a physiological rest position of the jaw.

Based on the results of recent experimental studies,²² the application of ULF-TENS for a single 60 minute session would reduce the electromyographic activity of masticatory muscles at rest, and would increase the interocclusal distance.



Figure 3 Electrode application on patient for neuromuscular TENS stimulation (right side).



Figure 4 Electrode application on patient for neuromuscular TENS stimulation (left side).



Figure 5 Electrode application on patient for neuromuscular TENS stimulation (nuchal area).

Several authors have evaluated the effect of ULF-TENS on electromyographic activity of masticatory muscles in TMD patients.

Cooper and Kleinberg³² concluded that ULF and low amplitude TENS applied for 60 minutes in TMD patients is able to relax the masticatory musculature and facilitate the detection of a physiological rest position of the jaw. Kamyszek *et al.*³³ evaluated the effects of ULF-TENS applied for 30–40 minutes in TMD patients with and without hyperactivity muscle at rest, with similar results in terms of reduction of

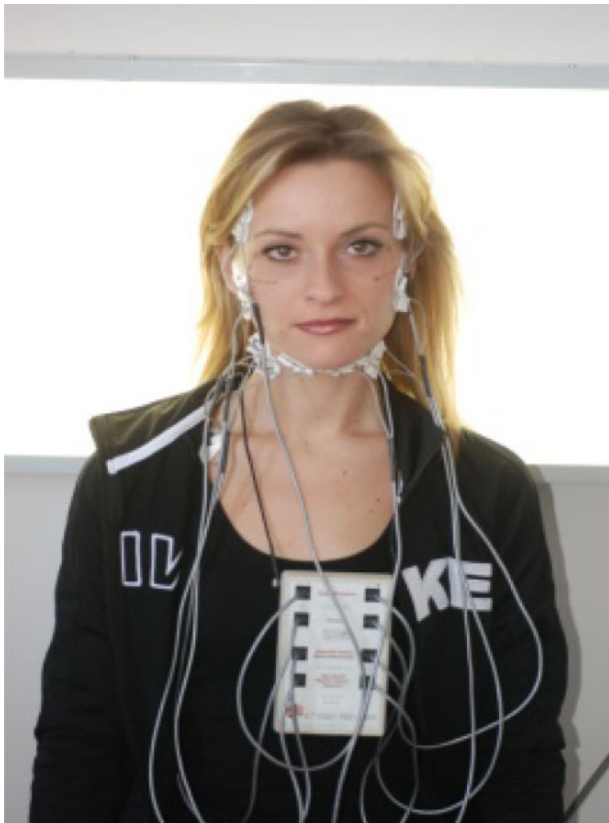


Figure 6 Patient after electrodes application for TENS and electromyography (EMG).

EMG activity of the stomatognathic musculature, in agreement with the results of Bazzotti.³⁵

Didier *et al.*³⁶ suggest the use of ULF-TENS in deprogramming the masticatory musculature aimed to identify the physiological rest position of the jaw in patients with chronic daily headache who must be subjected to neuromuscular therapy with occlusal devices. They stress the importance of ULF-TENS in deprogramming the muscles of the stomatognathic system in chronic daily headache patients with significant discrepancy of mandibular position, and the role of electrognathographic exams in highlighting this discrepancy.³⁶

Materials and Methods

For the current study, the PubMed database was used. The search strategy in the PubMed database was applied to the thesaurus Medical Subject Headings and it involved the following terms: ‘tens and tmd’ (*n*=18 articles found), ‘temporomandibular disorders and tens’ (*n*=1937 articles found), ‘transcutaneous electrical nerve stimulation and temporomandibular disorders’ (*n*=67 articles found), ‘transcutaneous electrical nerve stimulation and TMD’ (*n*=15 articles found), ‘craniomandibular disorders and transcutaneous electrical nerve stimulation’ (*n*=69 articles found), ‘craniomandibular disorders and tens’ (*n*=70 articles found), ‘tens and dentistry’ (*n*=238 articles found), ‘transcutaneous electrical nerve stimulation and dentistry’ (*n*=201 articles found).

All the articles selected from the PubMed database were manually analyzed by title, keywords, and abstract. The articles concerning the application of TENS in patients with bruxism or clenching were excluded from this review, as these events are anxious parafunctions with increased tension of the masticatory muscles, not classifiable as TMDs.

No randomized controlled trials on TENS application in TMD patients were found.

Only eight papers (CCT) found approval by the authors according to their relevancy on the debated topic (Table 1), so they were thoroughly examined.

Results

Examining the selected works, it was found that only four studies^{22,32,33,35} have investigated the effect of ULF-TENS on TMD patients: two studies^{37,38} (but with the same authors) evaluated the effect of conventional TENS on pain, masticatory muscle activity and activation pattern of TMD patients, one study²¹ focused on the effect of HF-TENS and LLLT on TMD patients, and one study¹⁶ evaluated

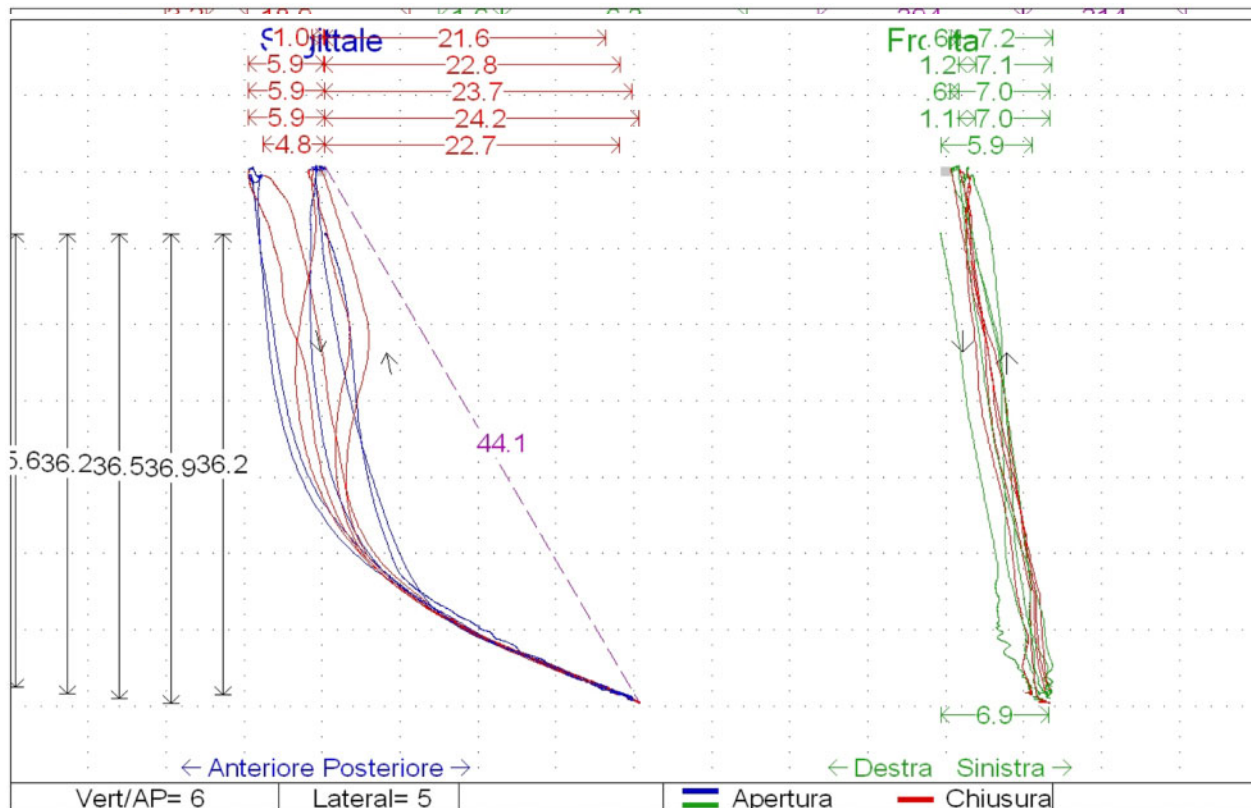


Figure 7 Patient DS, gender F, age 22: Scan 1 – electrognathographic track of maximum mouth opening (before TENS).

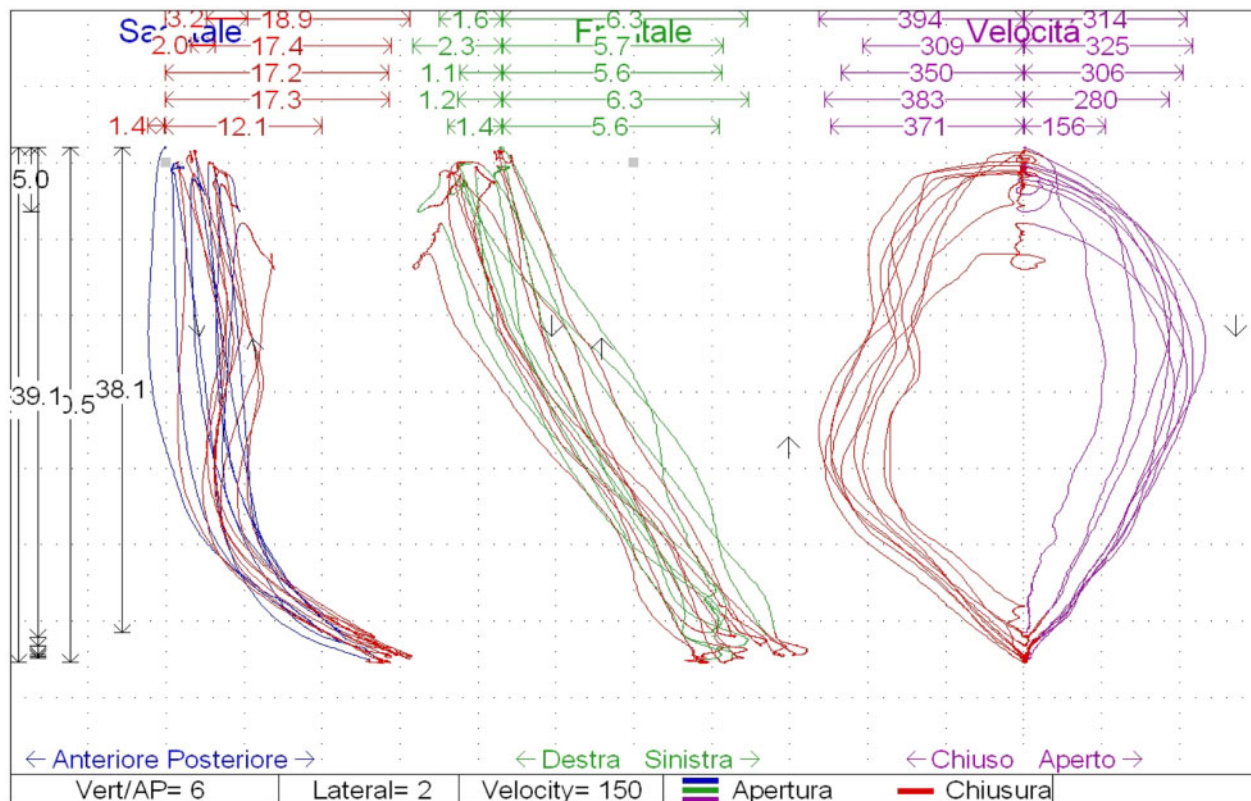


Figure 8 Patient DS, gender F, age 22: Scan 2 – electrognathographic track of speed of the movement performed by the mandible (before TENS).

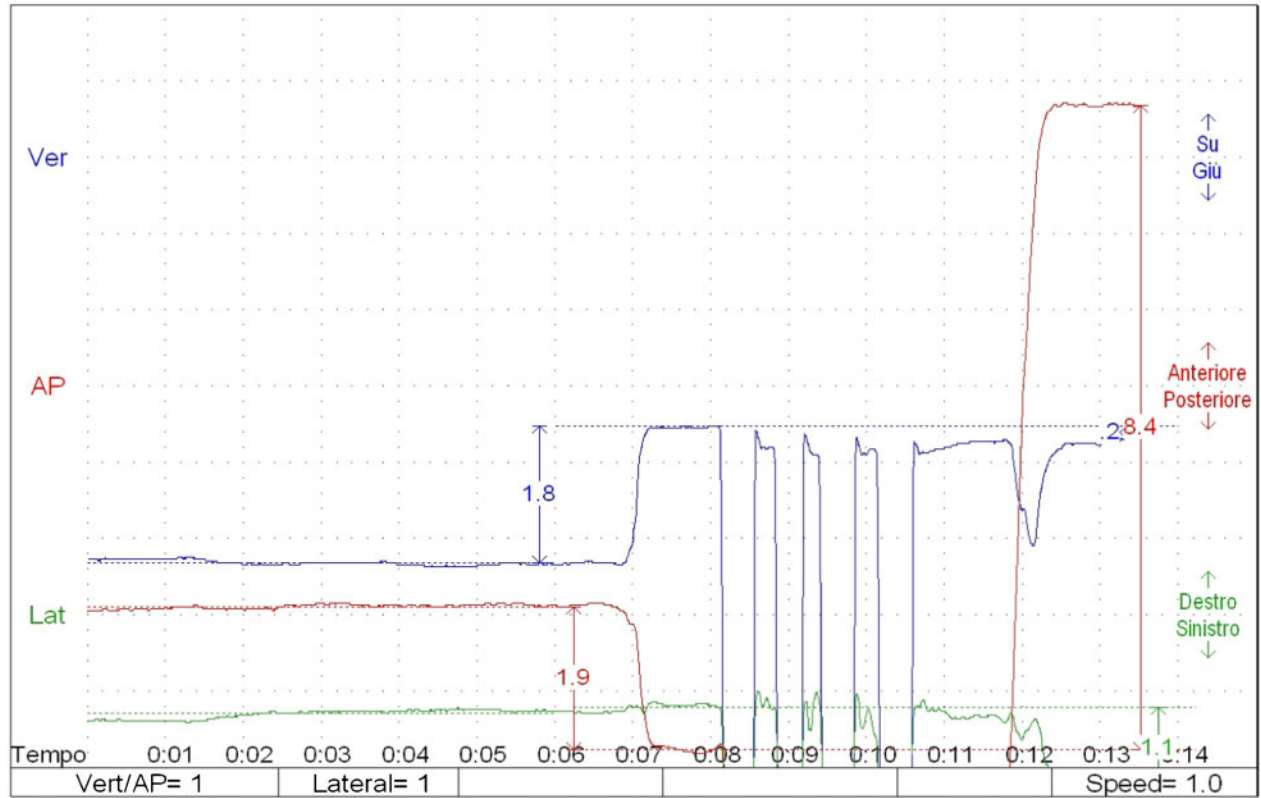


Figure 9 Patient DS, gender F, age 22: Scan 3 – electrognathographic track, which proposes the development over time of the mandibular movement (before TENS).

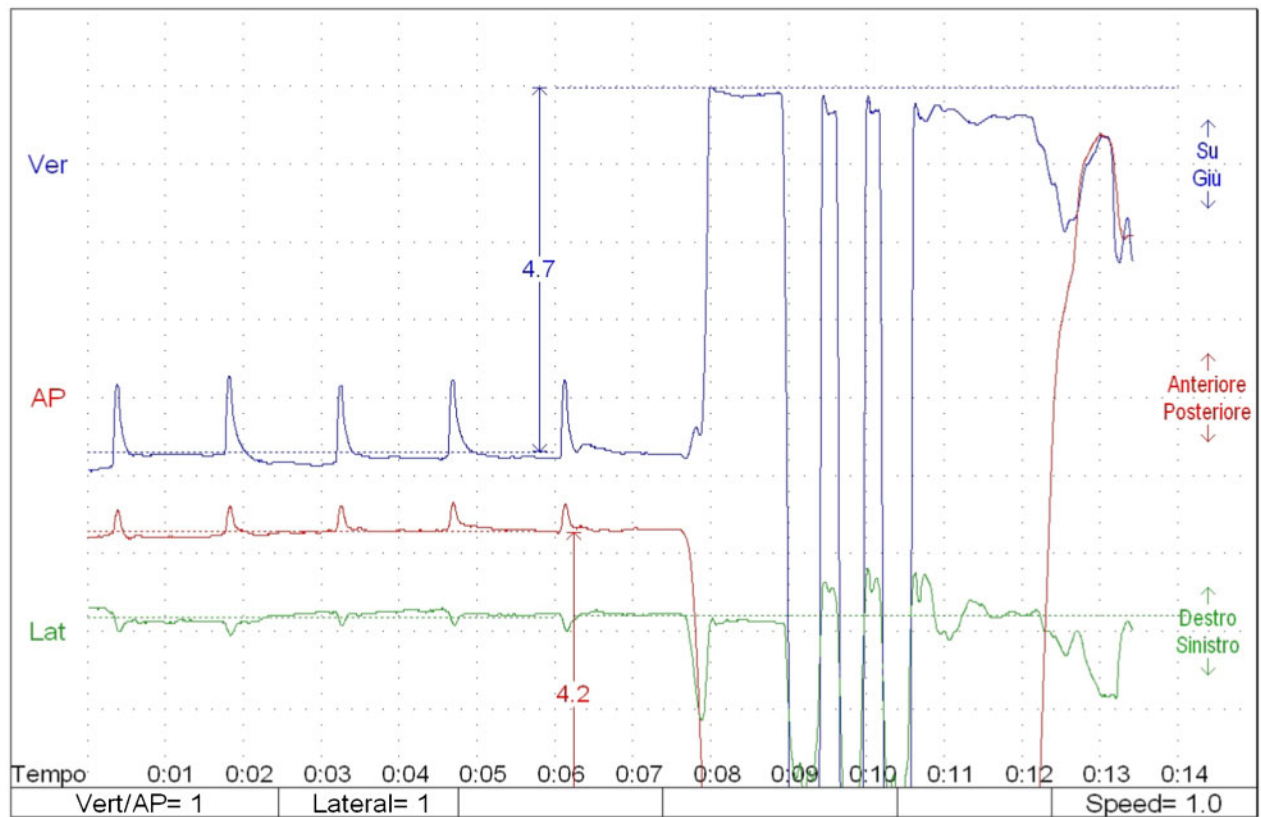


Figure 10 Patient DS, gender F, age 22: Scan 4 – electrognathographic track, which proposes the development over time of the mandibular movement (after TENS).

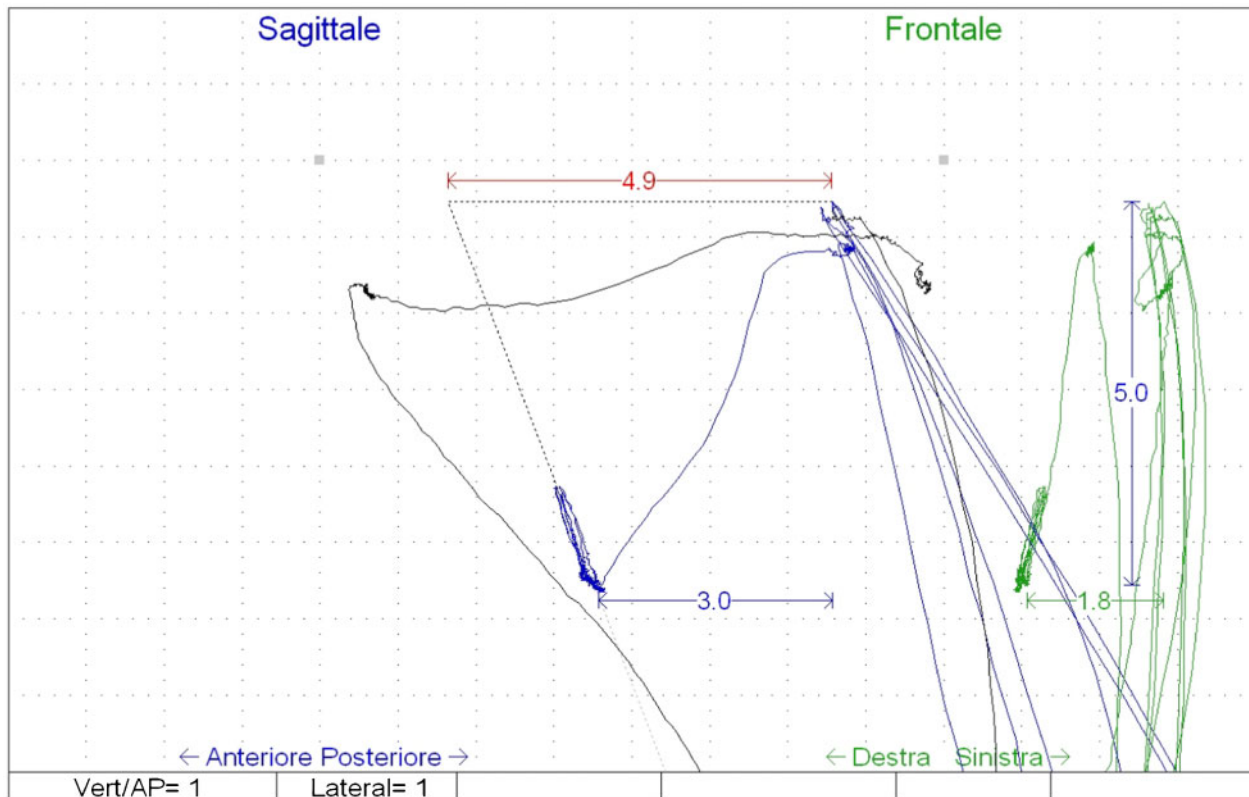


Figure 11 Patient DS, gender F, age 22: Scan 5 – transformation of scan 4 by the elimination of the time slider component (after TENS track).

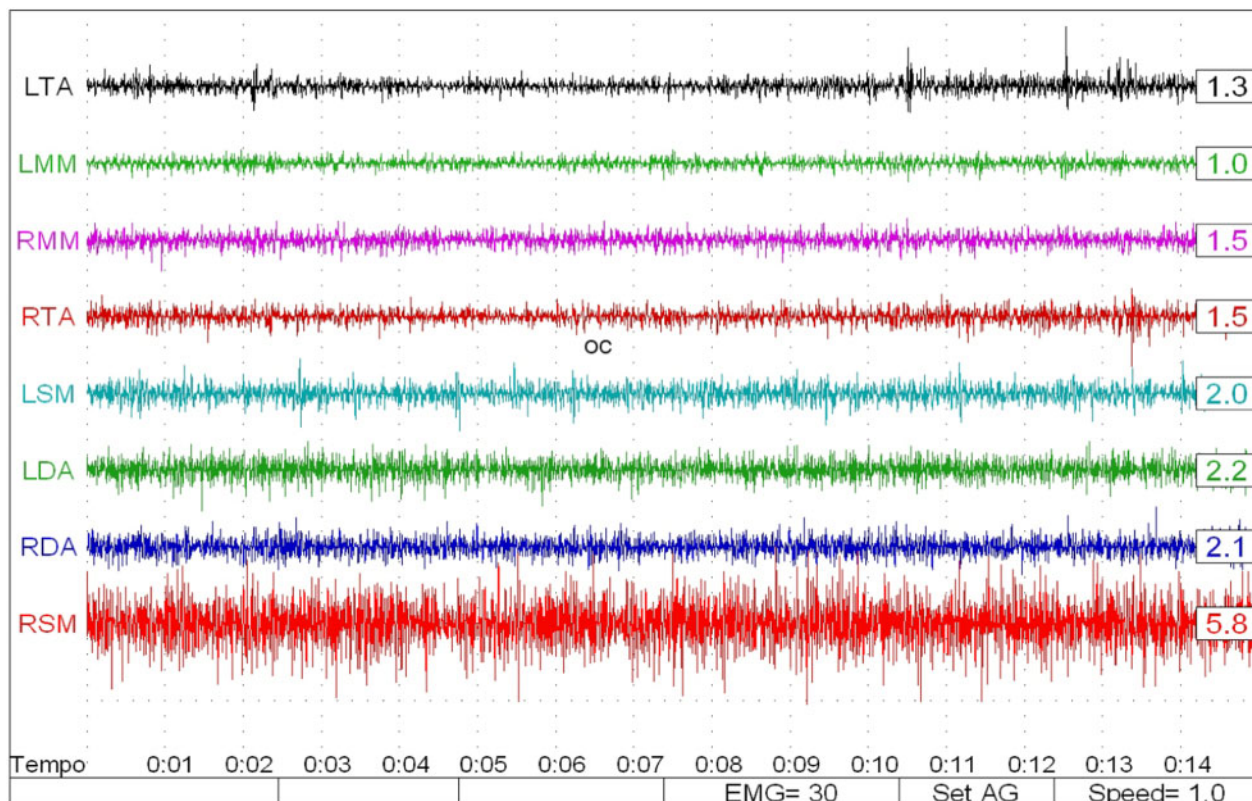


Figure 12 Patient DS, gender F, age 22: Scan 9 – EMG before TENS (with closed eyes).

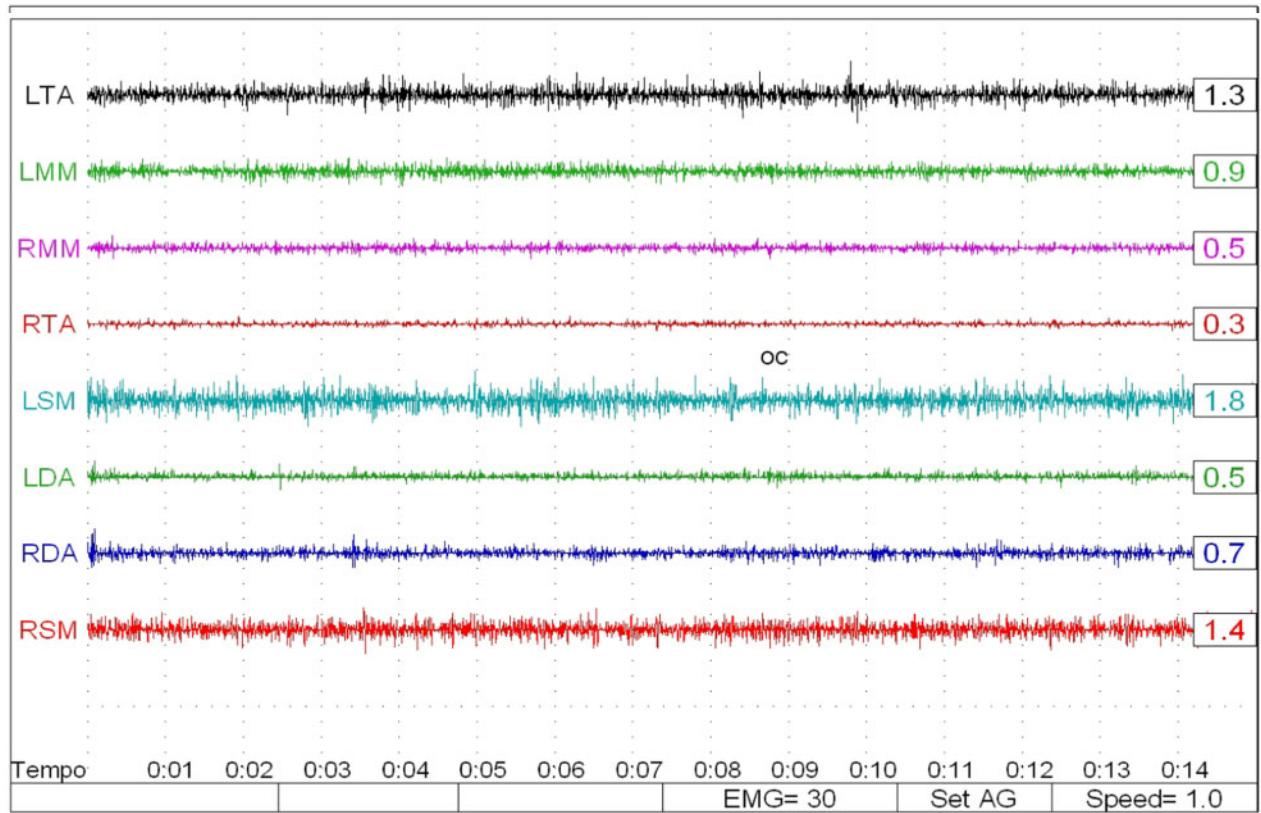


Figure 13 Patient DS, gender F, age 22: Scan 10 – EMG after 45 minutes of TENS (with closed eyes).

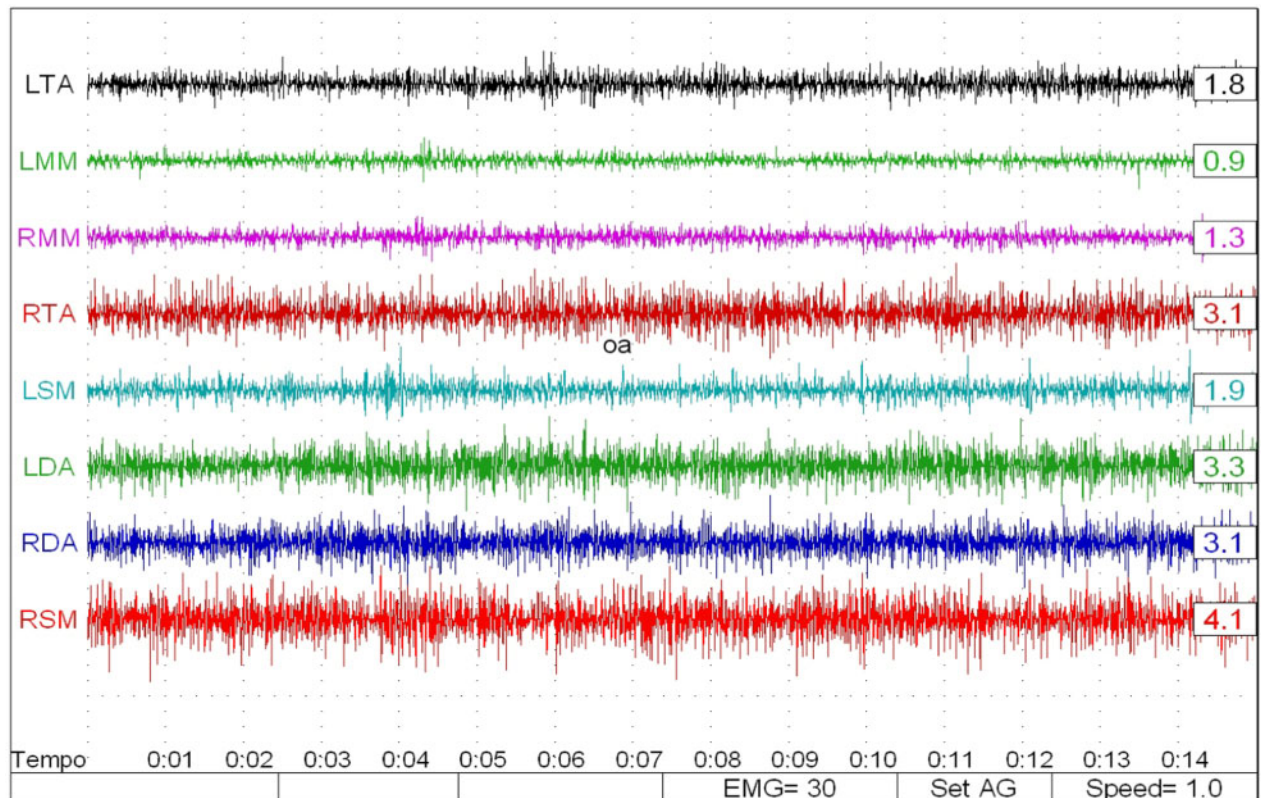


Figure 14 Patient DS, gender F, age 22: Scan 9 – EMG before TENS (with opened eyes).

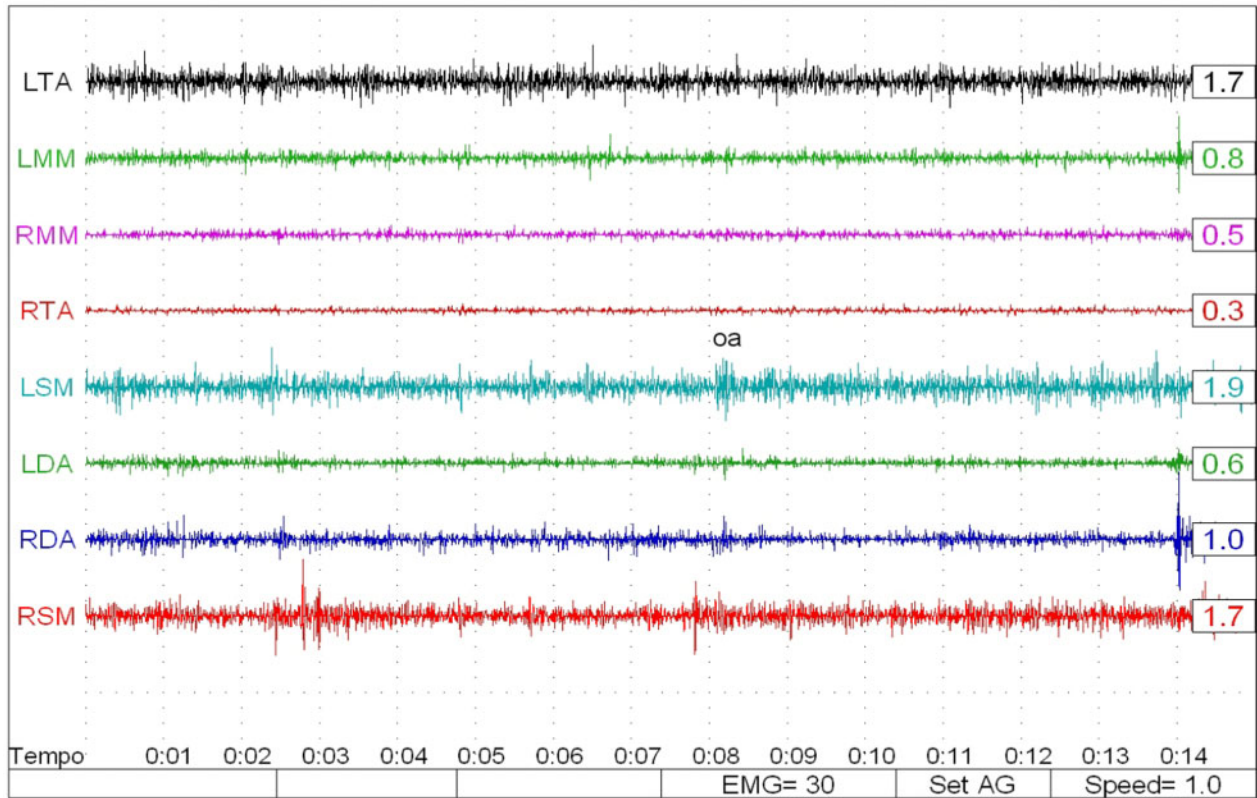


Figure 15 Patient DS, gender F, age 22: Scan 10 – EMG after 45 minutes of TENS (with opened eyes).

the effect of TENS (type of frequency not mentioned) and LLLT on TMD patients.

The authors, therefore, considered as experimental data for the purposes of this review only the studies of Monaco *et al.*,²² Cooper and Kleinberg,³² Kamyszek *et al.*,³³ and Bazzotti.³⁵

As can be seen from the results of the examined papers, in controlled clinical trials, ULF-TENS is able to relax the stomatognathic musculature, reducing its electromyographic activity in TMD patients.^{22,32,33} Although Cooper and Kleinberg,³² and Kamyszek *et al.*³³ evaluated the effect of ULF-TENS on electromyographic activity of masticatory muscles, reporting a decreased electromyographic activity of hyperactive

muscles, only one study²² also evaluated electrognathographic changes after ULF-TENS application. In fact, ULF-TENS is able to increase the vertical component of the interocclusal distance²² with the restoration of a ‘free-way’ space that is compatible with the physiology of the stomatognathic system.

Bazzotti³⁵ evaluated the relationship between Integrated EMG Activity (IEMG) and the frequency spectrum of certain muscles of the masticatory system at rest, both before and after relaxation induced by ULF-TENS. The results of Bazzotti’s study showed a significant decrease in IEMG values after ULF-TENS, and no influence of ULF-TENS on the frequency spectrum.

Table 1 Controlled clinical trials focused mainly on the effect of TENS on TMD patients

Authors and year of publication	Journal	Number of patients involved in the study	Main topic	Kind of TENS stimulation	Kind of trial
Monaco <i>et al.</i> , 2012 ²²	J Electromyogr Kinesiol	60	TENS and TMD	ULF-TENS	CCT
Cooper and Kleinberg, 2008 ³²	J Craniomandib Pract	313	TENS and TMD	ULF-TENS	CCT
Kato <i>et al.</i> , 2006 ¹⁶	J Appl Oral Sci	20	TENS and LLLT and TMD	Not mentioned	CCT
Núñez <i>et al.</i> , 2006 ²¹	Photomed Laser Surg	10	TENS and LLLT and TMD	HF-TENS	CCT
Rodrigues <i>et al.</i> , 2004 ³⁷	Braz Oral Res	35	TENS and TMD	Conventional TENS	CCT
Rodrigues <i>et al.</i> , 2004 ³⁸	Braz J Oral Sci	40	TENS and TMD	Conventional TENS	CCT
Kamyszek <i>et al.</i> , 2001 ³³	J Craniomandib Pract	29	TENS and TMD	ULF-TENS	CCT
Bazzotti, 1997 ³⁵	Electromyogr Clin Neurophysiol	52	TENS and masticatory muscles	ULF-TENS	CCT

As regards the frequency spectrum analysis, Thomas,³⁹ after evaluating the influence of TENS on the frequency spectrum, confirmed that the muscle fatigue induced by muscle exercise, was more efficaciously attenuated by TENS than by spontaneous rest.

As Cooper stated in the position paper of the International College of Cranio-Mandibular Orthopedics in 2011,¹ ULF-TENS is an active therapeutic device that affects relaxation of masticatory and mandibular postural muscles by use of low frequency, low current stimulation of the mandibular division of the trigeminal nerve and a branch of the superficial facial nerve. Transcutaneous electrical nerve stimulation is used during the treatment to achieve the true rest position of the mandible and a therapeutic neuromuscular occlusal position, and it is also employed as an aid in performing occlusal adjustments of the anatomical surface of the neuromuscular TMD orthosis.¹

Discussion

ULF-TENS application in neuromuscular gnathology has two functions:³⁴

1. to allow ULF-TENS to act as a controlled stimulus to test the general adaptive behavior of the system; the arising results and consequences should be considered as representative of local and systemic adaptation to the stomatognathic system manipulation;
2. to evaluate, specifically, the impact of the electric stimulation on the stomatognathic system, and generally on the adaptive system, in order to draw conclusions (or at least indications) on its use for diagnostic purposes, and for the craniomandibular relationship registration in gnathology.

The Jankelson's school of thought³¹ considers the 'rest position' (neutral position) as the key to the neuromuscular philosophy. The rest position defines the quality of the neuromuscular relationship existing between inferior and superior arches. It is the result of a close dynamic relationship between neuromuscular components (responsible for muscle tone) and viscoelastic components that are not expressed by muscle tone, but which can be investigated with ULF-TENS and computerized electrognathography.³⁴ Moreover, the muscle function is significantly greater within the zone of mandibular rest than at the intercuspal position.⁴⁰

ULF-TENS allows the release of the system by compensating occlusal constraints (related to the development or dental procedures), highlighting its neuro-muscular properties, and the realization of a physiological rest position through muscular relaxation and deconditioning.³⁴ A relaxed resting position

allows lower energy dispersion and a more ergonomic motion of the system each time the jaw comes out from the rest position to reach the occlusal contact.³⁴

In view of these considerations it is possible to employ ULF-TENS in the detection of occlusal vertical dimension in fully edentulous patients who must be rehabilitated by total mobile prosthesis. Hence, there are objective parameters resulting from electromyographic and electrognathographic analysis recorded before and after ULF-TENS, about the free-way space of edentulous patients, with identification of occlusal vertical dimension maintaining the neuromuscular pre-existing equilibrium. This avoids the delivery of prosthetic devices with vertical dimensions detected in an almost random way or based on maneuvers with a non-empirical rationale previously established, that could cause an iatrogenic injury to the stomatognathic system articular components, mainly in dysfunctional asymptomatic patients.

Faccioni *et al.*⁴¹ agree that the original vertical dimension of a patient can be determined by a series of tests, including electrognathography, electromyography, and transcutaneous electrical nerve stimulation.

Moreover, the observation of Cattaneo and Monaco,³⁴ in the outcome of Konchak's study,⁴² suggests a caution in the use of ULF-TENS in the case in which the effects of its administration could not be measured (through electromyographic and electrognathographic analysis). Konchak's study,⁴² in fact, shows that although ULF-TENS is able to increase the number of patients who can obtain a rest position with more 'relaxed' muscles, there are some patients who get worse after ULF-TENS (the EMG activity increases). This phenomenon happens because ULF-TENS is also a 'provocative' tool of the stomatognathic system, which allows the evaluation of the neuromuscular and viscoelastic reactions: in fact, both are expressed quantitatively through the electromyographic and electrognathographic data, allowing their interpretation in each specific context. The clinical experience of the authors showed that ULF-TENS effects are not always expressed with a 'muscle relaxation'. To assure the muscle relaxation, muscle rest activity must be recorded and analyzed.³⁴ The use of surface electromyography and computerized electrognathography without ULF-TENS seems incorrect because, according to Jankelson,³¹ the movement of mandible and the habitual rest tone of jaw muscles are adaptations to a pre-existing (pre ULF-TENS) condition. However, these statements must take into consideration the literature experimental results that, in the authors' consideration, are

enough for drawing conclusions, at least about the current state of the art of TENS effect on TMD patients. The authors also suggest further clinical and experimental investigations about this topic, to support the current findings.

Conclusions

According to examined papers, the authors can conclude that:

1. TENS is a therapeutic tool able to relax the stomatognathic muscles, to reduce the electromyographic activity of masticatory muscles at rest, and to increase the vertical component of the interocclusal distance in TMD patients.

2. TENS is able to facilitate the detection of a physiological rest position of the jaw.

3. The effects of TENS must be checked with sEMG and electrognathography.

4. Further studies are needed regarding the application of TENS in neuromuscular gnathology, mainly randomized controlled trials.

Disclaimer statements

Contributors All the authors contributed actively to this study: NC conceived, designed and wrote the paper, FS, AS, DP and CM performed the Pubmed search and articles analysis, and RC and AM reviewed the paper.

Funding These authors have no support or funding to report.

Conflicts of interest The authors declare that they have no conflict of interests.

Ethics approval This study was performed in accordance with the ethical principles of the World Medical Association's Declaration of Helsinki.

References

- Cooper BC. Temporomandibular disorders: A position paper of the International College of Cranio-Mandibular Orthopedics (ICCMO). *J Craniomandib Pract.* 2011;29(3):237–44.
- American Academy of Orofacial Pain: Assessment of orofacial pain disorders. In: Okeson JP, editor. *Orofacial pain: guidelines for assessment, diagnosis, and management.* Chicago, IL: Quintessence; 1996. p. 19–44.
- Dworkin SF, Leresche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomand Disord.* 1992;6:301–55.
- National Institute of Health Technology Assessment Conference Statement: Management of temporomandibular disorders. *J Am Dent Assoc.* 1996;127:1595–603.
- Plesh O, Sinisi SE, Crawford PB, Gansky SA. Diagnoses based on the Research Diagnostic Criteria for Temporomandibular Disorders in a biracial population of young women. *J Orofac Pain.* 2005;19(1):65–75.
- Manfredini D, Piccotti F, Ferronato G, Guarda-Nardini L. Age peaks of different RDC/TMD diagnoses in a patient population. *J Dent.* 2010;38(5):392–9.
- Gonçalves DA, Dal Fabbro AL, Campos JA, Bigal ME, Speciali JG. Symptoms of temporomandibular disorders in the population: an epidemiological study. *J Orofac Pain.* 2010;24(3):270–8.
- Sessle BJ. Evolution of the research diagnostic criteria for temporomandibular disorders. *J Orofac Pain.* 2010;24(1):5.
- Mackie A, Lyons K. The role of occlusion in temporomandibular disorders—a review of the literature. *N Z Dent J.* 2008;104(2):54–9.
- Maixner W, Greenspan JD, Dubner R, Bair E, Mulkey F, Miller V, et al. Potential autonomic risk factors for chronic TMD: descriptive data and empirically identified domains from the OPPERA case-control study. *J Pain.* 2011;12(11):T75–91.
- Fillingim RB, Ohrbach R, Greenspan JD, Knott C, Dubner R, Bair E, et al. Potential psychosocial risk factors for chronic TMD: descriptive data and empirically identified domains from the OPPERA case-control study. *J Pain.* 2011;12(11):T46–60.
- Monaco A, Cozzolino V, Cattaneo R, Cutilli T, Spadaro A. Osteopathic manipulative treatment (OMT) effects on mandibular kinetics: kinesiographic study. *Eur J Paediatr Dent.* 2008;9(1):37–42.
- Monaco A, Cattaneo R, Spadaro A, D'Andrea P, Marzo G, Gatto R. Ocular correction effects on EMG activity of stomatognathic muscles in children with functional mandibular lateral deviation: a case control study. *Eur J Paediatr Dent.* 2006;7(2):81–8.
- Monaco A, Cattaneo R, Spadaro A, Giannoni M, Di Martino S, Gatto R. Visual input effect on EMG activity of masticatory and postural muscles in healthy and in myopic children. *Eur J Paediatr Dent.* 2006;7(1):18–22.
- Monaco A, Cattaneo R, Mesin L, Ciarrocchi I, Sgolastra F, Pietropaoli D. Dysregulation of the autonomous nervous system in patients with temporomandibular disorder: a pupillometric study. *PLoS One.* 2012;7(9):e45424.
- Kato MT, Kogawa EM, Santos CN, Conti PC. TENS and low-level laser therapy in the management of temporomandibular disorders. *J Appl Oral Sci.* 2006;14(2):130–5.
- Madani AS, Mirmortazavi A. Comparison of three treatment options for painful temporomandibular joint clicking. *J Oral Sci.* 2011;53(3):349–54.
- Dym H, Israel H. Diagnosis and treatment of temporomandibular disorders. *Dent Clin North Am.* 2012;56(1):149–61. ix.
- Inchingolo F, Tatullo M, Marrelli M, Inchingolo AM, Tarullo A, Inchingolo AD, et al. Combined occlusal and pharmacological therapy in the treatment of temporomandibular disorders. *Eur Rev Med Pharmacol Sci.* 2011;15(11):1296–300.
- Petrucci A, Sgolastra F, Gatto R, Mattei A, Monaco A. Effectiveness of low-level laser therapy in temporomandibular disorders: a systematic review and meta-analysis. *J Orofac Pain.* 2011;25(4):298–307.
- Núñez SC, Garcez AS, Suzuki SS, Ribeiro MS. Management of mouth opening in patients with temporomandibular disorders through low-level laser therapy and transcutaneous electrical neural stimulation. *Photomed Laser Surg.* 2006;24(1):45–9.
- Monaco A, Sgolastra F, Ciarrocchi I, Cattaneo R. Effect of transcutaneous electrical nervous stimulation on electromyographic and kinesiographic activity of patients with temporomandibular disorders: a placebo-controlled study. *J Electromyogr Kinesiol.* 2012;22(3):463–8.
- Katch EM. Application of transcutaneous electrical nerve stimulation in dentistry. *Anesth Prog.* 1986;33(3):156–60.
- Sluka KA, Walsh D. Transcutaneous electrical nerve stimulation: basic science mechanisms and clinical effectiveness. *J Pain.* 2003;4(3):109–21.
- King EW, Sluka KA. The effect of varying frequency and intensity of transcutaneous electrical nerve stimulation on secondary mechanical hyperalgesia in an animal model of inflammation. *J Pain.* 2001;2(2):128–33.
- Gopalkrishnan P, Sluka KA. Effect of varying frequency, intensity, and pulse duration of transcutaneous electrical nerve stimulation on primary hyperalgesia in inflamed rats. *Arch Phys Med Rehabil.* 2000;81(7):984–90.
- Bandler R, Key KA, Floyd N, Price J. Central circuits mediating patterned autonomic activity during active vs. passive emotional coping. *Brain Res Bull.* 2000;53(1):95–104.
- Waters AJ, Lumb BM. Descending control of spinal nociception from the periaqueductal grey distinguishes between neurons with and without C-fibre inputs. *Pain.* 2008;134(1–2):32–40.
- Melzack R, Wall PD. Pain mechanisms: a new theory. *Science.* 1965;150(3699):971–9.

- 30 Galletti SP, Bergamini M, Pantaleo T. Highlights in the subject of low frequency-high intensity TENS (review). *Minerva Stomatol.* 1995;44(9):421–9.
- 31 Jankelson B. Electronic control of muscle contraction—a new clinical era in occlusion and prosthodontics. *Sci Educ Bull.* 1969;2(1):29–31.
- 32 Cooper BC, Kleinberg I. Establishment of a temporomandibular physiological state with neuromuscular orthosis treatment affects reduction of TMD symptoms in 313 patients. *J Craniomandib Pract.* 2008;26(2):104–17.
- 33 Kamyszek G, Ketcham R, Garcia R, Radke J. Electromyographic evidence of reduced muscle activity when ULF-TENS is applied to the Vth and VIIth cranial nerves. *J Craniomandib Pract.* 2001;19(3):162–8.
- 34 Cattaneo R, Monaco A. *Elettromiografia e chinesigrafia per la clinica odontoiatrica. Principi di odontoiatria neuro mio fasciale.* San Benedetto del Tronto: Futura Publishing Society; 2007.
- 35 Bazzotti L. Electromyography tension and frequency spectrum analysis at rest of some masticatory muscles, before and after TENS. *Electromyogr. Clin. Neurophysiol.* 1997;37:365–78.
- 36 Didier H, Marchetti C, Borromeo G, Tullo V, D’Amico D, Bussone G, et al. Chronic daily headache: suggestion for the neuromuscular oral therapy. *Neurol Sci.* 2011;32(1):S161–4.
- 37 Rodrigues D, Siriani AO, Bérzin F. Effect of conventional TENS on pain and electromyographic activity of masticatory muscles in TMD patients. *Braz Oral Res.* 2004;18(4):290–5.
- 38 Rodrigues D, Siriani AO, Bérzin F. Effect of tens on the activation pattern of the masticatory muscles in TMD patients. *Braz J Oral Sci.* 2004;3(10):510–5.
- 39 Thomas NR. The effect of fatigue and TENS on the EMG mean power frequency. *Front oral physiology. Vol. 7.* Basel: Karger; 1990. p. 162.
- 40 Hickman DM, Stauber W. Mapping mandibular rest in humans utilizing electromyographic patterns from masticatory muscles. *J Craniomandib Pract.* 2007;25(4):264–72.
- 41 Faccioni F, Laino A, Papadia D. Rehabilitation of partially edentulous patient with loss of vertical dimension. *Prog Orthod.* 2004;5:4–17.
- 42 Konchak P, Thomas N, Lanigan D, Devon R. Free way space measurement using mandibular kinesiograph and EMG before and after TENS. *Angle Orthod.* 1988;58:343–50.