A Review Article on Transcutaneous Electrical Nerve Stimulation (TENS)

Vaibhavi D
Dept of ECE
R V College of Engineering
Bengaluru, India
vaibhavid.ec23@rvce.edu.in

Tandle Suhani
Dept of ECE
R V College of Engineering
Bengaluru, India
tandlesuhani.ec23@rvce.edu.in

Tanmay Sharad Joshi
Dept of ECE
R V College of Engineering
Bengaluru, India
tanmaysj.ec23@rvce.edu.in

Dr Narendra Kumar S
Dept of Biotechnology
R V College of Engineering
Bengaluru, India
narendraks@rvce.edu.in

***Abstract*—Transcutaneous Electrical Nerve Stimulation (TENS) is a popular, non-invasive, and pharmacologically free method of pain management that consists of the application of low-voltage electrical currents into the body to stimulate peripheral nerves. This review discusses the modes of action, modes of application of TENS, clinical trials, and research directions for the therapy. Gate control theory and endogenous release of opioids are the major modes of action giving a physiological foundation to the action of TENS in different painful conditions. We address traditional, acupuncture-like, burst mode, and modulated TENS, and their individual roles in the management of chronic pain, postoperative pain, neuropathic pain, and dysmenorrhea. Safety issues, limitations, and new developments in TENS technology are also touched on. We are also solving for the convenience of use problem by proposing a way of applying the operation of TENS devices wirelessly(using ESP32) in a smaller and user-friendly implementation.**

***Index Terms*—Transcutaneous electrical nerve stimulation, pain management, gate control theory, endogenous opioids, chronic pain, dysmenorrhea, non-pharmacological therapy, wireless connectivity**

I. Introduction

Transcutaneous Electrical Nerve Stimulation (TENS) is a popular, non-invasive, and drug-free method of pain relief that involves the application of low-voltage electrical currents via the skin to activate peripheral nerves. Its greatest attraction is its portability, cost-effectiveness, simplicity of use, and minimal side-effect profile. TENS has also gained clinical favor as a single and adjunct treatment for acute and chronic pain conditions.

The underlying concept of TENS is that electrical stimulation of peripheral nerves can modulate pain messages and activate endogenous pain inhibitory mechanisms. Through controlled electrical currents to certain regions of the body, TENS attempts to decrease pain perception and enhance function, providing a non-pharmacological intervention in pain management approaches.

This article presents a broad overview of TENS, covering its mechanisms of action, forms, clinical use, safety factors, and future prospects. Through the review of existing evidence and new technologies, we hope to increase understanding of TENS as an important aid in the multi-disciplinary management of pain. We also present a brief design to use TENS as an IoT device based on an ESP32 microcontroller. This overcomes the challenge of making an easy user interface where the user can manipulate and interact with the device using a mobile phone.

II. Types of TENS

TENS is categorized based on frequency and intensity of stimulation, which influences its mechanism of action and clinical utility:

Traditional TENS with high frequency (50–100 Hz) and low intensity is mainly used to stimulate large-diameter A fibers, achieving pain relief via the gate control theory. It is widely utilized for the control of acute or superficial pain. Acupuncture-like TENS, on the other hand, utilizes low frequency (1–4 Hz) and high intensity to stimulate A fibers, which releases endogenous opioids such as endorphins, and hence is useful for chronic or deep pain.

Burst Mode TENS combines aspects of both traditional and acupuncture-like approaches, providing low-frequency bursts of high-frequency pulses. It is thought to provide more intense and longer-lasting analgesia, useful for chronic pain disorders. Finally, Brief Intense TENS involves high-frequency, high-intensity stimulation for a brief period in order to provide quick relief of pain, frequently employed clinically as a preoperative or preprocedure method for mitigating pain.

On the whole, TENS type choice should be determined by patient-specific pain characteristics, with tailored parameters to maximize treatment effects.

III. Mechanisms of Action

TENS relieves pain through two main physiological pathways:

A. Gate Control Theory of Pain

Suggested by Melzack and Wall (1965), this theory maintains that stimulation of large-diameter afferent fibers (A fibers) by TENS ”closes the gate” to nociceptive (pain) signals carried by small-diameter C and A fibers at the spinal cord level. This action is chiefly seen in the case of high-frequency (traditional) TENS, wherein the swift stimulation of sensory fibers blocks the carrying of pain messages at the dorsal horn of the spinal cord.

TABLE I
TYPES OF TENS AND THEIR CHARACTERISTICS

Type	Frequency (Hz)	Intensity	Pulse Duration	Targeted Nerve Fibers	Primary Mechanism	Typical Sensation	Clinical Applications
Conventional TENS	50–100 Hz	Low (sensory level)	50–80 µs	A fibers	Gate Control Theory	Tingling/vibration, no twitch	Acute & chronic pain, OA, LBP, postoperative pain
Acupuncture-like TENS	1–4 Hz	High (motor level)	100–400 µs	A fibers	Endogenous opioid release	Strong, rhythmic muscle twitch	Chronic pain, deep musculoskeletal pain, fibromyalgia
Brief Intense TENS	100–150 Hz	Very high (motor level)	150–250 µs	A and A fibers	Gate control + opioid release	Intense but tolerable, brief	Short procedures, wound dressing, labor, minor surgeries
Burst Mode TENS	1–4 bursts/sec (burst of 100 Hz pulses)	High (to motor level)	200–300 µs	A fibers in bursts	Opioid-mediated; combo of acupuncture and conventional	Tapping/pulsing sensation	Chronic pain, labor pain, neuropathic pain
Modulated TENS	Varies (automatically alternated)	Variable	Variable	Multiple	Prevents nerve accommodation	Changing sensations	Long-term treatment, tolerance management

B. Endogenous Opioid Release

Low-frequency TENS (1–10 Hz) stimulates mostly A fibers, stimulating release of endogenous opioids like endorphins and enkephalins. These naturally occurring substances interact with opioid receptors in the brain and spinal cord, modulating pain through descending inhibitory pathways. This mechanism forms the basis of acupuncture-like TENS, which is responsible for longer-duration analgesic effects than conventional TENS. Activations of opioid receptors by different forms of TENS have been found to be specific: low-frequency TENS through -opioid receptors and high-frequency TENS through -opioid receptors. This differential activation accounts for the diverse anal- gesic profiles and possible synergistic effects when using different TENS protocols

IV. CLINICAL APPLICATIONS

A. Chronic Pain Management

TENS has been shown to be effective in the treatment of a range of chronic pain conditions, such as osteoarthritis, fibromyalgia, and chronic low back pain. A number of randomized controlled trials (RCTs) and a Cochrane review by Johnson et al. (2022) assessed TENS for chronic pain and concluded that TENS sig- nificantly decreased pain intensity compared to placebo or no treatment. The authors, however, reported significant heterogene- ity between trials, and most studies were unblinded or had small sample sizes, which reduced the strength of the conclusions.

Factors affecting TENS efficacy in chronic pain include:

- Optimal parameter selection based on pain etiology
- Duration and frequency of application
- Electrode placement in relation to pain sites
- Individual patient responsiveness and tolerance
- Development of accommodation with prolonged use

B. Postoperative Pain

TENS has also been found useful in managing postoperative pain. When used at a high but tolerable intensity, it causes a significant decrease in both pain severity and use of supplementary analgesics. Wu et al. (2018) conducted a meta-analysis of the effects of TENS on postoperative pain in more than 40 RCTs. The review found that TENS lowered pain severity greatly and diminished the need for opioid analgesics, especially if used at a high intensity

C. Neuropathic and Central Pain

In the context of neuropathic and central pain conditions, TENS has been employed for cases such as diabetic neuropathy, postherpetic neuralgia, and central pain associated with multiple sclerosis. Clinical findings indicate that TENS can contribute to improved pain scores and enhanced quality of life in these patients, making it a viable non-pharmacological option for complex pain syndromes.

D. TENS for Dysmenorrhea

Painful menstruation, or dysmenorrhea, is an extremely common gynecological ailment that complicates a great percentage of menstruating women. TENS is now found to be an efficacious, innocuous, medication-free treatment alternative for primary dysmenorrhea (not provoked by pelvic disease).

1) Mechanism of Action in Dysmenorrhea:

1) **Gate Control Theory:** TENS activates large-diameter A sensory fibers, which inhibit the transmission of pain signals from uterine contractions to the spinal cord and brain.
2) **Endorphin Release:** Low-frequency TENS may stimulate the release of endogenous opioids (endorphins, enkephalins), enhancing pain inhibition and improving tolerance to menstrual cramps.

3) **Improved Blood Flow:** Some studies suggest TENS may increase local blood circulation, reducing ischemia-induced cramping pain in the uterus.

TABLE II
COMPARATIVE EFFICACY OF DYSMENORRHEA TREATMENTS

Treatment Modality	Efficacy	Onset of Relief
TENS	Effective in reducing pain in primary dysmenorrhea, especially with high-frequency TENS	Rapid (within 10–30 min)
Topical Heat Therapy	Comparable to or slightly better than NSAIDs in some studies for mild to moderate pain	Rapid (within 15–30 min)
NSAIDs (e.g., ibuprofen)	Gold standard; highly effective in most women	Moderate (1–2 hours)
Oral Contraceptives	Reduces severity/frequency of pain over time	Delayed (requires cycles)
Acupuncture	Some evidence for mild pain relief	Slow (needs sessions)
Diet/Lifestyle Modifications	Mild benefits; evidence not robust	Variable

2) Clinical Findings: Several studies have explored the effectiveness of TENS for dysmenorrhea:

- Proctor et al. (2002, Cochrane Review): TENS, especially high-frequency TENS, significantly reduced menstrual pain compared to placebo. It was found to be safe and effective for home use.
- Lee et al. (2013): High-frequency TENS was more effective than low-frequency TENS in relieving pain in primary dysmenorrhea.
- Akin et al. (2001): TENS provided rapid relief of pain with minimal side effects and was favored over NSAIDs by many users.

TABLE III
RECOMMENDED TENS PARAMETERS FOR DYSMENORRHEA

Parameter	Typical Range
Frequency	70–100 Hz (high-frequency preferred)
Intensity	Low to moderate (sensory threshold, comfortable tingling)
Pulse Width	50–100 s
Duration	20–30 minutes per session; 2–3 sessions/day as needed
Electrode Placement	Lower abdomen or lower back (T10–L1 dermatomes)

3) Recommended TENS Parameters for Dysmenorrhea: Limitations and factors of using TENS for dysmenorrhea are that its effectiveness may be lower in females with secondary dysmenorrhea, e.g., due to endometriosis. Although TENS tends to be well tolerated, mild side effects can occur with users, e.g., skin irritation or discomfort at the point of stimulation. These should be considered when assessing whether TENS is an appropriate pain management option.

V. SAFETY AND ADVERSE EFFECTS

TENS is generally thought to be a safe treatment with very few risks. The most frequently noted side effects are minor skin irritation, allergic sensitivity to adhesives or electrodes, and temporary discomfort from electrical stimulation. It does have some particular contraindications, though.

- TENS should not be applied over pacemakers or implanted defibrillators
- Generally advised to avoid its use in pregnant women, particularly over the abdominal area
- Individuals with epilepsy should not use TENS without proper medical supervision
- Caution is advised in patients with impaired sensation or cognitive ability
- TENS should not be applied over areas of broken skin, recent scar tissue, or regions with malignancy

Education on device usage and parameter adjustment is important to prevent untoward effects and optimize therapeutic advantages. Continuous monitoring of skin condition with electrodes and regular stimulation parameter adjustment may assist in ensuring safety and efficacy with long-term TENS.

VI. DISCUSSION AND FUTURE DIRECTIONS

A. Discussion

The current body of evidence supports TENS as a versatile, non-pharmacological modality for pain management across a broad range of conditions. Its dual mechanisms—modulation of nociceptive signals through the gate control theory and stimulation of endogenous opioid release—provide a strong physiological foundation for its analgesic effects. Clinically, TENS has demonstrated significant potential in managing both acute and chronic pain, including postoperative, neuropathic, and musculoskeletal pain. The ability for patients to self-administer TENS, along with its favorable safety profile, contributes to its popularity in both clinical and home settings. Nevertheless, the literature reveals variability in study designs, TENS parameters (frequency, intensity, electrode placement), and outcome measurements, which complicates the generalizability and reproducibility of findings. There is also evidence that prolonged use may lead to the development of tolerance, reducing long-term effectiveness unless parameters are varied.

B. Future Directions

To optimize TENS therapy and further substantiate its clinical value, several research directions are necessary:

- **Standardized Treatment Protocols:** Developing and validating standardized guidelines for TENS parameters based on pain types and patient profiles could improve treatment consistency and outcomes.
- **Long-Term Efficacy Studies:** More robust, high-quality longitudinal studies are needed to assess sustained efficacy, optimal usage duration, and potential tolerance development.

- **Mechanistic Studies:** Greater insights into the neurophysiological pathways involved in TENS will help refine applications and tailor therapy for complex pain conditions.
- **Combinatorial Therapies:** Exploring TENS in combination with other treatments (e.g., physiotherapy, pharmacologic interventions, or cognitive behavioral therapy) may yield synergistic effects.

C. Proposed Innovations

Innovation in TENS technology can enhance its clinical effectiveness, accessibility, and patient experience:

- **Wireless Mobile-Controlled TENS Device with ESP32 Integration and Dual Control Interface:**
  The proposed solution integrates an ESP32 microcontroller connected to a mobile device to wirelessly control the TENS device through bluetooth or Wi-Fi. The mobile device communicates with the ESP32 to set 2 PWM signals for intensity and frequency control. These signals are smoothed into an analog voltage using an RC low-pass filter (1k resistor and 1uF capacitor). This analog voltage is then buffered to ensure signal stability and drive capability. The processed control voltage enters the TENS control circuitry, where two potentiometers allow manual adjustment of intensity and frequency. Together, these components enable both mobile controlled and manual tuning of the TENS device for safe and effective electrical stimulation

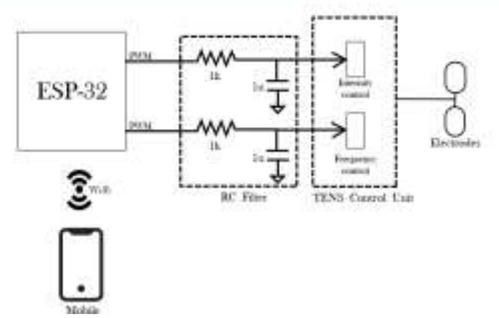

Fig. 1. Schematic diagram of the ESP32-based wireless TENS control system showing the mobile interface, Wi-Fi connectivity, RC filters, and electrode connections.

- **Smart TENS Devices:** Incorporating AI and biofeedback sensors to dynamically adjust stimulation parameters based on real-time patient response (e.g., skin impedance, muscle tension, or subjective pain ratings).
- **Wearable TENS Systems:** Lightweight, wireless, app-integrated wearables can improve usability and compliance, especially for chronic pain patients requiring frequent treatments.
- **Personalized Stimulation Protocols:** Algorithms that customize frequency, intensity, and duration based on individual patient data (age, condition, skin type, etc.) can increase effectiveness and minimize tolerance.
- **Multi-Modal Pain Management Platforms:** Combining TENS with other non-invasive modalities such as heat therapy, vibration, or cold stimulation in a single device may offer comprehensive pain relief tailored to user preferences.

VII. Conclusion

Transcutaneous Electrical Nerve Stimulation represents an important non-pharmacological approach to pain management with applications spanning acute, chronic, neuropathic, and specific pain conditions like dysmenorrhea. The physiological mechanisms underlying TENS efficacy provide a scientific basis for its continued use and development in clinical practice. While current evidence generally supports TENS as an effective intervention, particularly for certain pain conditions, further research is needed to optimize treatment protocols, understand long-term effects, and develop innovative technologies that enhance therapeutic outcomes. As healthcare continues to emphasize multimodal pain management strategies, TENS remains a valuable component in the comprehensive approach to improving pain control and quality of life for patients across diverse clinical populations.

The ongoing evolution of TENS technology, coupled with refined clinical protocols and deeper physiological understanding, promises to expand its utility and effectiveness in the future landscape of pain management.

References

[1] Johnson MI, Paley CA, Jones G, Mulvey MR, Wittkopf PG. "Efficacy and safety of transcutaneous electrical nerve stimulation (TENS) for acute and chronic pain in adults: a systematic review and meta-analysis of 381 studies (the meta-TENS study)." BMJ Open. 2022;12(2):e051073.

[2] Sluka KA, Walsh D. "Transcutaneous electrical nerve stimulation: basic science mechanisms and clinical effectiveness." J Pain. 2003;4(3):109-121.

[3] Vance CG, Rakel BA, Dailey DL, Sluka KA. "Using TENS for pain control: the state of the evidence." Pain Manag. 2014;4(3):197–209.

[4] Mehendale, N., & Inamdar, M. "A Review on Transcutaneous Electrical Nerve Stimulation and its Applications". SSRN. 2020.

[5] Proctor ML, Smith CA, Farquhar CM, Stones RW. "Transcutaneous electrical nerve stimulation for primary dysmenorrhoea." Cochrane Database Syst Rev. 2002;(1):CD002123.

[6] Lee B, Hong SH, Kim K, Kim J, Kim JH. "Effectiveness of high-frequency transcutaneous electrical nerve stimulation for primary dysmenorrhea: A randomized controlled trial." J Obstet Gynaecol Res. 2013.

[7] Akin MD, Weingand KW, Hengehold DA, Goodale MB, Hinkle RT, Smith RP. "Continuous low-level topical heat in the treatment of dysmenorrhea". Obstet Gynecol. 2001.

[8] Melzack R, Wall PD. "Pain mechanisms: a new theory." Science. 1965;150(3699):971-979.

[9] Wu J, Hu Y, Zhu Y, Yin P, Litscher G, Xu S. "Systematic Review of Adverse Effects: A Further Step towards Modernization of Acupuncture in China." Evid Based Complement Alternat Med. 2018;2018:6769108.

[10] Cleveland Clinic. "Transcutaneous Electrical Nerve Stimulation (TENS)." Available from: https://my.clevelandclinic.org/health/treatments/15840-transcutaneous-electrical-nerve-stimulation

[11] G. Ernst and A. Lee, "Safety issues in TENS therapy," J Electrotherapy, vol. 29, no. 3, pp. 157–162, 2020.

[12] M. Fornasari, "Tolerance to TENS therapy," Pain Research and Treatment, vol. 2020, pp. 1–6, 2020.

[13] B. Kaplan, D. Rabinerson, S. Lurie, J. Bar, U. Krieser, A. Neri, Transcutaneous electrical nerve stimulation (tens) for adjuvant pain-relief during labor and delivery, International Journal of Gynecology Obstetrics 60(3), 251 (1998)
[14] F. Moran, T. Leonard, S. Hawthorne, C.M. Hughes, E. McCrum-Gardner, M.I. Johnson, B.A. Rakel, K.A. Sluka, D.M. Walsh, Hypoalgesia in response to transcutaneous electrical nerve stimulation (tens) depends on stimulation intensity, The Journal of Pain 12(8), 929 (2011)
[15] T. Donvito, Transcutaneous electric nerve stimulation (tens) for arthritis pain: Does it help? (2020)
[16] C. Rakel and C. Barr, ”Post-op analgesia using TENS,” Pain Management Nursing, vol. 18, no. 2, pp. 110–118, 2020.
[17] M. DeSantana et al., ”Brain activation patterns during TENS,” Pain Medicine, vol. 22, no. 4, pp. 621–628, 2021.
[18] V. Kasat, A. Gupta, R. Ladda, M. Kathariya, H. Saluja, A.A. Farooqui, Transcutaneous electric nerve stimulation (tens) in dentistry-a review, Journal of clinical and experimental dentistry 6(5), e562 (2014)
[19] Gozani SN, Ferree TC, Moynihan M, et al. Impact of transcutaneous electrical nerve stimulation on sleep in chronic low back pain: a real-world retrospective cohort study. J Pain Res 2019;12:743–52.
[20] K. Leonard et al., ”Opioid-mediated mechanisms of TENS,” Clin J Pain, vol. 31, no. 8, pp. 647–654, 2019.
[21] William Gibson 1, Benedict M Wand, Neil E O’Connell., ”Transcutaneous electrical nerve stimulation (TENS) for neuropathic pain in adults” Clin J Pain, vol. 31, no. 8, pp. 647–654, 2019.
[22] Matthew R Mulvey,Carole Paley , ”Efficacy and safety of transcutaneous electrical nerve stimulation (TENS) for acute and chronic pain in adults: a systematic review and meta-analysis of 381 studies (the meta-TENS study)” Clin J Pain, vol. 31, no. 8, pp. 647–654, 2019.