Proceedings of ICMMGH 2025 Workshop: Computational Modelling in Biology and Medicine
DOI: 10.54254/2753-8818/90/2025.GU21054

Percutaneous Electrical Nerve Stimulation (TENS) in Postoperative Rehabilitation of the Anterior Cruciate Ligament (ACL)

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Abstract: Anterior cruciate ligament (ACL) injury is a common knee injury, and pain management and functional recovery after its reconstruction is an important part of the rehabilitation process. Transcutaneous electrical nerve stimulation (TENS), as a non-invasive method of pain management, has been widely used in a variety of clinical scenarios, especially during postoperative recovery. This review studies the application of TENS in ACL postoperative rehabilitation and analyses its effects on pain control, functional recovery and patient satisfaction. The results showed that TENS significantly reduced postoperative pain after, and ACL reduced patients' need for opioids. It also has a positive effect on functional recovery. So, TENS as a pain management modality shows potential in postoperative rehabilitation after ACL, especially in pain management and early functional recovery. Nevertheless, the optimal parameter settings (e.g., frequency, intensity, and treatment duration) and long-term effects of TENS remain controversial. Future studies need to explore the optimal application parameters and evaluate its long-term effectiveness and cost-effectiveness.

Keywords: Transcutaneous Electrical Nerve Stimulation (TENS),Pain Management,ACL Postoperative Rehabilitation,Anterior Cruciate Ligament (ACL) Injuries,Functional Recover

1. Introduction

As participation in sport continues to grow, the occurrence of anterior cruciate ligament (ACL) injuries is increasingly affecting the general population. Approximately 85 per 100,000 people between the ages of 16 and 39 are affected [1] and while rehabilitation after ACL reconstruction typically takes 6 to 1 year, pain in the acute period postoperative is one of the major factors affecting the recovery process, and few patients have pain persistent postoperative. Effective pain control can reduce patient anxiety, enhance motivation for rehabilitation, and promote functional recovery.

TENS is one of the most used electrotherapy methods for pain control and can be used to relieve postoperative pain, post-traumatic pain, dysmenorrhea, peripheral nerve injury, angina pectoris, metastatic bone pain, chronic low back pain, chronic neck pain, headache, osteoarthritis, and pain during pregnancy, childbirth, and the postpartum period [2]. In addition, early physiotherapy for patients with low back pain following an emergency room visit can save money and healthcare costs [3]. Other direct physical interventions including acupuncture, massage, and transcutaneous electrical

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nerve stimulation (TENS) may have a role to play in the management of acute pain in ED patients, but there is currently less data available, and costs must be considered. In a small pilot study conducted in the ED, the TENS unit was effective in relieving pain in 99% of cases [4]. The aim of this paper is to analyze the use of TENS in postoperative rehabilitation of ACL and its effects to provide a practical clinical reference.

2. Classification and parameters of TENS

TENS can be classified into the following types depending on the frequency and intensity of stimulation:

Conventional TENS, with a frequency range of 50-150 Hz, is primarily used for acute pain management with rapid onset of action through a gating mechanism.

Needle-like TENS (low frequency/high intensity) has a frequency range of 1-10 Hz, mainly pain over stimulation of deep tissues, and is suitable for chronic pain with more long-lasting effects [5].

Burst TENS, with a pulse frequency of 70-100 Hz, combines the theory of and the gating starvation of the opioid system the endogenous with dual effect of rapid onset and sustained analgesia [6].

In addition, the current intensity (milliamp level), pulse width (typically 50-250 microseconds) and treatment time (20-60 minutes per session) need to be adjusted according to the individualized needs of the patient [7].

3. Theoretical background

3.1. Physiological of TENS

TENS relieves pain through peripheral and central mechanisms. It has been shown that TENS regulates pain-related ion channels, such as voltage-gated sodium channels, to inhibit injury receptor neurotransmission [8]. Centrally, TENS activates downstream inhibitory pathways the periaqueductal grey matter (PAG), the ventral medial head of the medulla oblongata (RVM), and the spinal cord, which reduces pain signals in the dorsal horn of the spinal cord in [8]. High-frequency TENS increases β-endorphin and methionine enkephalins, which interact with opioid receptors and decrease the release of glutamate and substance P, thus potentially reducing central sensitization. Low-frequency TENS also activates GABA-A, muscarinic receptors and 5-hydroxytryptamine [9]. The frequency of TENS affects receptor mediation: low-frequency treatments predominantly activate μ-opioid receptors, whereas high-frequency treatments involve the δ-opioid receptor, a distinction that is significant for opioid users as low-frequency TENS is likely to have a lesser effect [10]. In addition, blockade of peripheral α-2A adrenergic receptors diminish the analgesic effect of TENS [9]. Overall, TENS provides a versatile approach to pain management by activating multiple pathways and receptors.

3.2. Classification and parameters of TENS

Understanding the parameters of TENS enables better personalization of the treatment plan, these parameters include frequency, intensity, pulse width and position of the electrodes. Below are a few key points: for adjusting a plan TENS treatment

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Placement of electrodes at or near the site of pain is often recommended in clinical practice, and while it has long been recognized that TENS has a distal analgesic effect, a recent study has demonstrated a new use for TENS distal stimulation for a wide range of pain relief applications. Instead of placing electrodes at the pain site, TENS distal stimulation was applied to a site that is homologous to the contralateral side of the pain site, to a site that is distant from the pain site but is innervated by overlapping spinal cord segments, and to an unrelated extraneous site. The study provides evidence to support the distal analgesic effect of traditional TENS by reviewing more than 30 animal studies, experimental human pain studies, and clinical studies. The combination of TENS and traditional Chinese medicine with tendon and acupoints has also given us new ideas for treatment, as TENS electrodes can be placed on acupoints, motor points, or trigeminal points, as well as on the area of most intense pain, appropriate dermatomes, or spinal nerves [12]. In a clinical study transcutaneous electrical acupoint stimulation therapy for osteoarthritison , it was found that TEAS (Transcutaneous Electrical Acupoint Stimulation Therapy) stimulation of the Fengchi, Neiguan, and Hegu acupoints suppressed the release of inflammatory factors and S100-β protein in the early postoperative period after TKA (Total Knee Arthroplasty), which resulted in a reduction of perioperative neurocognitive deficits in elderly patients with TKA, as well as a further enhancement of analgesic effects.

3.3. Status of research

TENS therapy is recognized for its clinical analgesic use. Despite the low quality of evidence in some studies, TENS has shown significant efficacy and safety in a variety of pain management scenarios. Future studies should further optimize the parameter settings of TENS and explore its efficacy in different pain types, especially the mechanism and application of distal analgesic effects. In addition, technological innovations such as the application of wireless technology and 3D printing technology will provide new directions for the portability and personalization of TENS.

Studies have shown that the effects of TENS in total knee arthroplasty (TKA) present a significant reduction in pain during walking in the TENS group, which helps to restore functional gait. In addition, a prospective study by Xie Rong et al. found that TENS, combined with conventional postoperative rehabilitation, significantly improved knee mobility, get-up-and-go time, and Knee Scale Score (KSS) scores in postoperative TKA patients.

However, another systematic review reported TENS and a comparison between. The quality of the evidence was very low, meaning that we were unable to determine whether TENS was effective for pain control in patients with neuropathic pain. Nevertheless, the use of TENS in chronic pain management remains widespread, particularly in reducing medication dependence and providing non-pharmacological treatment options placebo.

TENS, as a non-invasive analgesic therapy, due to its non-invasive, has a promising future in clinical practice low-risk, simple operation, no risk of addiction, and low adverse effects in the field of acute and chronic pain management with high patient acceptance. Complications associated with TENS are rarely reported. Singla et al. did not find any adverse effects [13], which supports the safety of TENS.

Differences in treatment effects between patients are closely related to individual patient characteristics (e.g. age, gender, type of pain) and the of parameter settings (the treatment frequency, intensity, pulse width, etc.) Individualized therapeutic prescriptions for TENS will be a key direction for research.

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4. Research challenges and controversies

Although there has been some research on the use and effectiveness of TENS in several areas, it continues to face several challenges and controversies.

The efficacy of TENS varies across studies; some patients may respond significantly to TENS treatment, while others may have a poor outcome. Therefore, how to optimize treatment regimens according to individual characteristics is an urgent issue to be addressed

Besides, there are no recognized uniform standards for a particular pain modality, resulting in varying, with TENS treatment parameters across studies some limitations on the of comparability and generalizability studies.

Although TENS has shown good short-term efficacy, its long-term effects remain unclear. Some studies suggest that the efficacy of TENS may diminish over time, and some patients may develop dependence on treatment after long-term use. How to ensure that TENS treatment continues to be effective in the long term without compromising patient compliance is an important research challenge.

Moreover, the cost-effectiveness of TENS analyses should also be improved. In 2009, experts from the French National Health Authority reported on an evaluation of TENS devices [14], highlighting the fact that TENS is particularly useful for chronic pain that cannot be satisfactorily relieved by medication alone. They pointed out several advantages of TENS. In addition to safety, TENS devices are moderately costly compared to other technologies, including implantable neurostimulators, but more data is still needed on how to assess cost-effectiveness in long-term treatment.

5. Conclusions

In summary, TENS has some application value in ACL postoperative rehabilitation, especially in postoperative pain control, relieving patients' psychological stress and reducing opioid use. However, the current data on TENS dedicated to ACL postoperative rehabilitation are scarce, and more high-quality studies are needed to further validate its effects and mechanisms. In the future, other technologies (e.g., ultrasound, 3D printing, virtual reality, etc. Combined) should be and interdisciplinary collaboration pursued to explore more efficient and innovative treatment modalities. For example, in combination with 3D printing technology, TENS electrodes can be customized to match the patient's body shape and pain points, thus improving the individualization of treatment.in order. Research should focus on the specific mechanisms of TENS and personalized optimal treatment parameters to optimize its use in postoperative ACL rehabilitation to help more patients.
Not only that, the increasing aging of the global population and the rising prevalence of chronic pain disorders such as arthritis, low back pain, and neuropathic pain have led to a significant increase in the demand for pain management solutions, and it is believed that the market for TENS devices will expand significantly in the future.

In the future, TENS machines may be equipped with more advanced sensing technology to monitor the patient's pain level in real time and automatically adjust the electrical stimulation parameters to achieve more accurate pain management. Meanwhile, combined with mobile internet and artificial intelligence technologies, TENS machines can be networked with smart devices for remote monitoring and data analysis to optimize treatment plans.

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