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Research Progress of Transcutaneous Acupoint Electrical Stimulation in Perioperative Applications

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Abstract

Transcutaneous Electrical Acupoint Stimulation (TEAS), as a non-invasive treatment method, has been increasingly applied in the perioperative period due to its simplicity, non-invasiveness, and high patient acceptance. It has shown certain effects in reducing postoperative complications and promoting postoperative recovery. This review summarizes the research progress of TEAS in perioperative analgesia, improvement of neurocognitive disorders, immune function regulation, alleviation of sleep disturbances, promotion of postoperative recovery, and organ protection, aiming to provide more reference for its clinical application.

Keywords: Transcutaneous Acupoint Electrical Stimulation, perioperative, pain, autonomic nervous system, stress

1. Introduction

Since the beginning of the 21st century, with the progress of medical technology and the improvement of living standards, the number of surgeries has been increasing year by year, and people's pursuit of safety and comfort during the perioperative period has gradually increased. The perioperative period refers to the entire process from preoperative preparation to postoperative recovery, including the preoperative preparation stage, the intraoperative maintenance stage, and the postoperative recovery stage. Perioperative management is a complex and necessary process that involves the cooperation of multiple disciplines and requires the joint efforts of surgeons, anesthesiologists, and nurses. By optimizing perioperative management, not only can the patient's hospital experience be improved, but the quality of postoperative recovery can also be significantly enhanced (SIBLEY D, SELLERS D, RANDALL I, et al., 2023). Improving the perioperative experience for patients, reducing the pain, tension, anxiety, and postoperative adverse reactions they experience during medical treatment, thereby providing comfortable and reliable medical services (KOLCABA K Y., 1992). People's demands during the perioperative period mainly focus on pain management, psychological support, rapid postoperative

recovery, and the medical environment and services. During surgery or examinations, patients expect effective pain management to alleviate or eliminate pain; at the same time, an increasing number of people are paying attention to psychological comfort, hoping that medical staff can help reduce anxiety and fear, and relieve psychological stress (Teng Yunpeng & Xue Rongliang, 2023). In addition, rapid postoperative recovery is also an important part of people's medical needs. Patients hope to recover quickly after surgery, shorten their hospital stay, and return to normal life as soon as possible.

Transcutaneous Electrical Acupoint Stimulation (TEAS) is an innovative treatment method developed based on Transcutaneous Electrical Nerve Stimulation (TENS). TEAS integrates traditional Chinese medicine theories with modern technology, regulating Qi and blood, balancing Yin and Yang, and promoting recovery by electrically stimulating specific acupoints, thereby enhancing patient comfort during the perioperative period. Its theoretical foundation includes core concepts of traditional Chinese medicine such as meridians, Qi and blood, Yin-Yang balance, and holistic views (Lou Xinfa & Jiang Songhe, 2012). The mechanism of action of TEAS is closely related to neural pathways. It activates acupoints through electrical stimulation, regulates the transmission of nerve signals, and thereby affects the central nervous system and peripheral nerve functions to exert analgesic, anti-inflammatory, and autonomic regulatory effects. In terms of acupoint selection, TEAS is designed based on the "meridians" and "collaterals" in traditional Chinese medicine theory. Although these theories have not yet been fully validated by modern anatomy and histology, clinical practice has proven their effectiveness in the treatment of various diseases. This article aims to review the mechanism of action of TEAS and its research progress in perioperative applications, and to explore its potential value in improving the patient medical experience.

2. Mechanism of Action of TEAS

2.1 Analgesic Effect

The analgesic mechanisms of TEAS are primarily based on two theories: the Gate Control Theory and the Endogenous Opioid Peptide Theory (DELEO J A., 2006).

The Gate Control Theory posits that TEAS exerts its analgesic effect by inhibiting the transmission of peripheral pain signals to the central nervous system. There are two types of nerve fibers in the skin and tissues: one type is the thick fibers (Aβ fibers) that convey peripheral tactile and pressure sensations, and the other type is the thin fibers (Aδ and C fibers) that transmit peripheral pain and temperature sensations. There is a mutual inhibitory phenomenon between thick and thin fibers in signal transmission. TEAS stimulates the thick fibers, thereby inhibiting the pain transmission of the thin fibers, achieving the goal of pain relief.

The Endogenous Opioid Peptide Theory suggests that TEAS can promote the release of endogenous opioid peptides (MAYOR D., 2013), and different stimulation frequencies vary in promoting the release of opioid peptides in the central nervous system and the activation of major opioid receptors (CHEN X H & HAN J S., 1992). Low-frequency electrical stimulation may activate μ and δ opioid receptors in the spinal cord more, producing more endogenous opioids such as enkephalins and endorphins, mainly exerting analgesic effects through spinal neural pathways. High-frequency electrical stimulation, on the other hand, works more through κ opioid receptors, affecting neural pathways in both the spinal cord and the brain. Studies have shown that high-frequency (100 Hz) electroacupuncture stimulation can promote the release of dynorphins in the spinal cord (XIANG X H, CHEN Y M, ZHANG J M, et al., 2014), and a previous molecular biology study proved that endogenous dynorphins have a strong antinociceptive effect in the spinal cord (CHENG H Y, PITCHER G M, LAVIOLETTE S R, et al., 2002). Additionally, Ji-Sheng Han (1992) used antagonists for these three types of opioid receptors in his research, and the results showed that the analgesic effect produced by electroacupuncture was greatly reduced after the use of antagonists, further confirming that electrical stimulation exerts analgesic effects through the production of endogenous opioids. Josimari M. DeSantana's research found (2008) that alternating low and high-frequency sparse-dense waves can produce a stronger analgesic effect, and the development of tolerance to opioids is also slower compared to single-frequency electrical stimulation.

2.2 Regulation of Autonomic Nervous System Function

Anxiety is the most common psychological

health issue among patients in the perioperative period (GANDARELA L, DE A. SAMPAIO T P, MARçAL L, et al., 2024), and it is also a major cause of many adverse effects on patients, with excessive anxiety affecting surgical outcomes and increasing the risk of readmission. Therefore, it is very necessary to reduce the stress and anxiety levels of patients in the perioperative period. Anxiety is usually caused by dysregulation of the autonomic nervous system, with overactivation of the sympathetic nervous system or inhibition of the parasympathetic nervous system manifesting as an anxious state. The mechanism by which TEAS reduces preoperative anxiety may be achieved by regulating the levels of endogenous factors such as serotonin, norepinephrine, and cortisol (WU X, CHEN T, WANG K, et al., 2023). Recently, many studies have pointed out that the amygdala is a key emotional processing structure, and the functional connection between the frontal lobe regions of the brain and the amygdala is an important process for emotion management (LIU J, FANG J, WANG Z, et al., 2016). TEAS can regulate the functional connectivity disorders between the two, and by comparing the resting state and the functional magnetic resonance imaging results after one month of using TEAS, it was found that the functional connectivity of the amygdala-frontal lobe region network increased significantly, resulting in a marked reduction in anxiety and depression scores and improvement in symptoms. Additionally, TEAS can regulate other cortical and subcortical structures that affect emotions, such as the anterior cingulate cortex, locus coeruleus, and medial prefrontal cortex (ARANBERRI RUIZ A, 2024).

Heart Rate Variability (HRV) is one of the important indicators of autonomic nervous function. M Khawar Ali et al. (2023) analyzed 73 articles on the autonomic function of functional gastrointestinal diseases such as gastroesophageal reflux disease and irritable bowel syndrome and found that in these patients, HRV usually shows reduced parasympathetic activity or increased sympathetic activity. By monitoring changes in HRV, TEAS can increase vagal excitability, reduce sympathetic excitation, and improve gastric slow-wave motility to promote the recovery of gastrointestinal function (HU Y, ZHANG B, SHI X, et al., 2020). Wei Gao et al. (2021) conducted a multicenter randomized controlled trial and found that TEAS significantly reduced the incidence of postoperative paralytic ileus. Patients who received TEAS treatment had a noticeable increase in serum acetylcholine levels within 72 hours postoperatively, indicating that TEAS may promote the recovery of gastrointestinal function after surgery by activating the vagus nerve.

2.3 Neurochemical Mechanisms

TEAS may exert its effects by influencing the secretion of hormones and neurotransmitters. Yong-Liang Chi et al. (2019) found in a study of elderly patients undergoing knee surgery that TEAS could reduce the levels of cortisol, adrenocorticotropic hormone, and C-reactive protein in the blood, alleviate perioperative stress and inflammatory responses, and accelerate postoperative recovery in elderly patients. Additionally, TEAS can improve mood by affecting the levels of neurotransmitters in the brain (WU X, CHEN T, WANG K, et al., 2023), such as promoting the release of serotonin and dopamine to combat preoperative anxiety and depression. Studies have shown that TEAS can act on the brain-gut axis (BAI Y-F, GAO C, LI W-J, et al., 2020), which connects the central nervous system with the enteric nervous system, by reducing the secretion of substance P and vasoactive intestinal polypeptide, promoting the secretion of motilin and cholecystokinin, thereby affecting the sensory, motor, and endocrine patterns of the gastrointestinal tract, as well as promoting the recovery of postoperative gastrointestinal function by affecting the gut microbiota.

2.4 Organ Protection

TEAS plays a protective role in organ function during the perioperative period. There are many factors during surgery that can cause brain damage, such as reduced cerebral blood flow due to hypotension, anemia, and vasospasm, ischemia-reperfusion injury, and direct damage to cerebral blood vessels and brain tissue from the surgery itself. The key pathological mechanisms involved are oxidative stress and inflammation (CHEN G, WANG X, JIN Z, et al., 2024). Intraoperative brain injury can affect the patient's neurologic function, such as limb weakness, speech disorders, or sensory disturbances, and can even cause permanent disability. Therefore, close cooperation between surgeons, anesthesiologists, and the nursing

team is needed to reduce its occurrence. A study in a middle cerebral artery occlusion/reperfusion (MCAO/R) rat model found that TEAS can significantly reduce neuronal apoptosis, neuroinflammation, and oxidative stress injury in the hippocampus of MCAO/R rats by activating silent information regulator factor 1 (SIRT1), thereby reducing brain damage (TAN Z, DONG F, WU L, et al., 2024). TEAS preconditioning can alleviate ischemia-reperfusion injury in rats by regulating microglial polarization and neuroinflammation through the Nrf2/HO-1 signaling pathway (LI J, HAO M, LIU M, et al., 2022). TEAS can exert pulmonary protective effects by reducing oxidative stress during one-lung ventilation. Studies have shown that TEAS can lower the levels of malondialdehyde in the serum during thoracoscopy surgery, increase the activity of superoxide dismutase, and improve oxygenation indices during one-lung ventilation (JU S, LIU M, WANG B, et al., 2023).

3. Clinical Applications of TEAS in the Perioperative Period

TEAS, which combines the traditional Chinese medicine concept of acupuncture with modern electrical stimulation technology, is mainly applied in the perioperative period in the following areas:

3.1 Postoperative Analgesia

Currently, common pain management techniques include pharmacological treatment, nerve blocks, epidural analgesia, physical therapy, and patient-controlled analgesia (PCA) (RAJ P, SINHA N, KHARWAR R K, et al., 2024). Pain medications have significant analgesic effects, but they also come with relatively more side effects, such as increased damage to liver and kidney functions, nausea, and vomiting. Nerve blocks and epidural analgesia are invasive procedures that can be highly stimulating to patients and require a high level of technical skill from the operating physician. Multimodal analgesia is currently the most recommended approach, as it targets different types and intensities of pain by selecting different analgesic techniques and anesthetic drugs with different mechanisms of action to achieve a more ideal analgesic effect (BAEZ C, PRIETO H A, TISHAD A, et al., 2024). A meta-analysis including 17 clinical randomized controlled trials involving 1,375 subjects showed (WANG D, SHI H, YANG Z, et al., 2022) that patients treated with TEAS had significantly lower pain scores 24 hours after surgery, and the amount of postoperative opioid analgesics used was also significantly reduced, while the occurrence of adverse events such as dizziness, nausea, and vomiting was also decreased. Clinical trials have proven that using TEAS 30 minutes before surgery can fully activate the body's endogenous analgesic system, producing various endogenous opioid substances, thereby reducing the need for analgesic and sedative drugs and increasing patient comfort (JIANG M, WANG B, LIU M, et al., 2024). TEAS can significantly reduce pain scores within 48 hours after thoracoscopy surgery, and the number of patients requiring rescue analgesia within 24 hours after surgery is also significantly reduced (LIU J, ZHANG K, ZHANG Y, et al., 2024). TEAS has a definite analgesic effect, relatively fewer adverse reactions, minimal stimulation, and a protective effect on the body's organs, potentially becoming an important part of multimodal analgesia.

3.2 Regulation of Autonomic Nervous System Function

Mustafa Al-Zamil et al. (2024) conducted high-frequency and low-frequency electrical stimulation directly on the right median nerve to observe its effects on anxiety disorders. The results showed that patients who received electrical stimulation had significantly reduced scores on the 7-item Generalized Anxiety Disorder scale and the Hamilton Anxiety Scale, and their symptoms were also significantly alleviated within six months. Postpartum Depression (PAYNE J L & MAGUIRE J., 2019) is a common psychological disorder in women after childbirth. Current research suggests that postpartum depression is mainly related to changes in hormone levels, sleep quality, psychological stress, and dysregulation of the autonomic nervous system. The application of TEAS with different frequencies during childbirth has a positive effect on hormone levels, pain perception, and anxiety levels (SULU R, AKBAS M & CETINER S., 2022). High-frequency TEAS can promote the release of oxytocin and endorphins, reduce the level of cortisol in the blood, inhibit sympathetic nerve stimulation of the vagus nerve, and play a positive role in the postoperative recovery of mothers. Yong-Liang Chi et al. (2019) found in their study of elderly patients undergoing knee surgery that TEAS could accelerate patient

recovery by reducing perioperative stress and inflammation levels. A meta-analysis summarizing 12 randomized controlled trials involving 1,347 patients showed (JIANG M, WANG B, LIU M, et al., 2024) that the mean arterial pressure and heart rate of patients in the TEAS group were significantly lower than those in the control group immediately after extubation and up to 10 minutes later. The extubation process was more stable, reducing the stress response triggered by extubation and decreasing the risk of postoperative agitation and delirium. Patients who received TEAS had significantly lower levels of high-sensitivity troponin T postoperatively and improved heart rate variability indicators, indicating that TEAS can reduce postoperative myocardial damage and improve autonomic function (LI H, WU C, YAN C, et al., 2019).

TEAS applied in patients with sleep disturbances during the perioperative period can significantly reduce inflammatory responses and improve postoperative sleep quality. Data shows that more than 40% of patients exhibit sleep disturbances on the first postoperative day, and sleep issues may persist for several days (CHOUCHOU F, KHOURY S, CHAUNY J-M, et al., 2014). Decreased sleep quality can lead to numerous harms, such as exacerbating patients' anxiety and irritability, inducing Postoperative Delirium (POD), reducing immunity, and delaying postoperative recovery. TEAS can stimulate specific acupoints, thereby activating the nervous regulatory system, which helps regulate the neurotransmitters in the brain related to sleep, thus improving patients' sleep quality (WEI W, HUANG X & ZHU J., 2023).

3.3 Improving Neurocognitive Function

TEAS contributes to the improvement of neurocognitive dysfunction that patients may experience during the perioperative period. Kai-Yu Huang et al. (2023), through an analysis of 12 clinical studies involving 991 patients, concluded that TEAS can reduce the incidence and duration of postoperative delirium, significantly improving the quality of patients' postoperative recovery. Fei Guo et al. (2023) conducted a meta-analysis of 12 clinical randomized controlled studies on the treatment of postoperative delirium with TEAS in recent years, showing that TEAS can protect neurons, reduce neuroinflammatory responses, and decrease the dosage of anesthetic drugs, thereby reducing the incidence of delirium within one week after surgery. Both meta-analyses demonstrated the significant effect of TEAS in improving postoperative cognitive dysfunction in patients. The randomized controlled trials involved used various scoring tools and blood indicators to assess postoperative delirium, and the comparative results all showed a significant therapeutic effect of TEAS, increasing the credibility of the findings. However, there are few more direct examinations such as imaging studies and electroencephalograms, and research in these areas should be increased to more objectively reflect the treatment effects.

3.4 Promoting Postoperative Recovery

A meta-analysis including 10 clinical studies involving 2,383 patients showed (ZHANG M, ZHANG H, LI P, et al., 2024) that TEAS can reduce the use of intraoperative opioid drugs and postoperative PCA, decrease the occurrence of postoperative nausea and vomiting, enable early recovery of gastrointestinal absorption and digestion functions, and enhance the patient's body resistance. For some orthopedic surgeries, such as total knee arthroplasty (TKA), early postoperative activity is crucial for the quality of patient recovery. The introduction of TEAS not only reduces adverse reactions from analgesic drugs but also plays a positive role in improving postoperative knee joint function (ZHANG L., 2024). The micturition reflex is mainly controlled by the autonomic nervous system; anticholinergic drugs and anesthetics can inhibit parasympathetic activity, leading to postoperative urinary retention. TEAS balances autonomic nervous function, increases the release of the micturition reflex messenger urinary ATP, and reduces the occurrence of urinary retention (HUANG K-Y, LIANG S, DU H-G, et al., 2024).

3.5 Organ Protection

TEAS contributes to the stability of liver and kidney function during the perioperative period by improving blood circulation, reducing oxidative stress, and exhibiting anti-inflammatory effects, thereby reducing the risk of ischemia-reperfusion injury (YANG X, FENG Z & CAI M., 2024). The endorphins released by TEAS not only play a role in controlling pain and reducing stress but also promote the dilation of bronchioles, alleviating dyspnea and lowering the incidence of postoperative pulmonary complications (CHEN J, ZHANG Y, LI X, et al., 2020). A meta-analysis

shows that TEAS can significantly reduce myocardial damage and protect the heart through various mechanisms, promoting the recovery of cardiac function and stabilizing circulation, with a reduction in the amount of vasoactive drugs used (ASMUSSEN S, PRZKORA R, MAYBAUER D M, et al., 2017).

3.6 Enhancing Patient Satisfaction

Patients, while focusing on the quality of treatment, also hope for the lowest possible hospitalization costs and the shortest possible hospital stays. Yilong Liu et al. through a meta-analysis of 34 clinical randomized controlled trials, demonstrated that TEAS can significantly reduce the length of hospital stay and hospitalization costs, and increase patient satisfaction (LIU Y, FAN J, ZHANG X, et al., 2024). Whether postoperative ICU stay is necessary and the duration of ICU stay are also concerns for patients. TEAS significantly improves the Quality of Recovery (QOR-15) scores on the first and second days after surgery, markedly reducing ICU stay and postoperative hospital days (JU S, LIU M, WANG B, et al., 2023). TEAS can reduce the occurrence of postoperative adverse events through the aforementioned mechanisms, decrease additional hospitalization costs and length of stay due to the management of complications, and enhance patient trust and satisfaction.

4. Summary and Prospects

The advantages of TEAS lie in its combination of the essence of traditional Chinese medicine and modern technological innovation, providing patients with a safer and more efficient treatment method. However, in current clinical research, the selection criteria for acupoint pairing in TEAS lack scientific standards, often relying on previous studies without clinical guidelines. Therefore, future research needs to focus more on large-sample, multicenter studies that concentrate on parameters and standardized selection of acupoints. This research should reveal the mechanisms of TEAS at the cellular and molecular levels, making the application of TEAS in the perioperative period more quantifiable, standardized, systematic, and objective.

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