REVIEW

Transcutaneous Electrical Nerve Stimulation: An Alternative Approach to the Management of Postoperative Pain

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The management of postoperative pain has been and continues to be a significant problem in surgical practice in terms of both the additional stress it places on the patient's physiologic reserves and the symptomatic discomfort it causes. It is well known by practitioners that pain is an individual experience and this fact is reflected in a wide variation in the incidence and severity of pain and in the need for analgesics. A number of factors including age, anesthetic technique, personality of the patient, previous experience, physical status, site of operation, and surgical management affect the incidence of postoperative pain (1, 2).

In light of the problems associated with postoperative pain, various strategies for the management of pain have been proposed. The most commonly used method stresses the use of systemic analgesics, narcotics, and related drugs. Regional analgesia offers an attractive alternative to the use of narcotics and tranquilizers in that respiratory depression and sedation are avoided and the patient can be made pain free for extended periods using long-acting local anesthetics.

Regional analgesia is not without problems, however, and its use requires the presence of an anesthesiologist who is skilled in regional block techniques and who is prepared to treat the occasional complication that may develop. Recently, the use of epidural morphine has been advocated for the treatment of postoperative pain (3). The advantages of epidural morphine included prolonged analgesia and lack of sympathetic or motor block. Unfortunately, epidural morphine also has its disadvantages. Generalized itching, urinary retention, respiratory depression, and respiratory arrest occurring up to 10 hours after injection have been reported (4, 5).

Within the last decade, there have been a small but increasing number of reports concerning the use of transcutaneous electrical nerve stimulation (TENS) for the relief of postoperative pain. This paper presents a review of these reports.

History

Historically, the use of electrical analgesia is an ancient technique. Electrical fish were first used to provide electricity for pain relief (6–8). The torpedo fish or electric ray, which is capable of emitting 200 V, was used by Greek and Roman physicians in the treatment of gout, headaches, and other ailments as far back as 46 AD. This method apparently involved bringing the patient's affected part into contact with the enraged fish, which was contained in a bucket of water. Indeed, electrical stimulation was sporadically used in the 17th and 19th centuries. Its use was
limited, however, by the technology of the time and overshadowed by simultaneous advances in the pharmacologic treatment of pain (7). Only recently have developments in the fields of electronics and neurophysiology allowed the development and clinical application of safe, reliable, and portable electrical stimulating devices.

Initially, TENS was introduced as a screening procedure to determine which patients were suitable for surgical placement of dorsal column stimulators for pain relief. Although unsuccessful in this application, it was noted that TENS produced local analgesia and that it might be useful therapeutically in and of itself in patients with chronic pain.

There are now sufficient studies available in the literature to assess the value of TENS in the treatment of both chronic and acute pain. Externally applied electrical stimulation is now in common use in most pain treatment programs and is gradually gaining acceptance in the treatment of postoperative pain.

Theory

The use of afferent stimulation techniques, often called neuromodulation, is based on application of the gate control theory of pain originally advanced by Melzack and Wall (9) in 1965. Briefly, the gate control theory postulates that impulse transmission from afferent nerve fibers to the spinal cord transmission cells is modulated by a spinal gating mechanism in the substantia gelatinosa. The relative amounts of activity in the large myelinated A-beta fibers and small A-delta and C fibers influence the gating mechanism in a way such that large fiber activity inhibits transmission (closes the gate) while small fiber activity facilitates transmission (opens the gate). In addition, a central biasing mechanism receives information over a rapidly conducting large fiber system and further modulates the gating mechanism via descending fibers, thus allowing cognitive processes to influence pain perception.

The rationale for the use of electrical stimulation to produce analgesia is based upon the premise that stimulation of large peripheral nerve fibers closes the spinal gate and thus prevents painful peripheral stimuli from gaining access to the ascending transmission system. In support of this theory is the observation that large myelinated fibers have a low threshold to electrical stimulation (10). TENS is believed to inhibit the relay of painful stimuli by causing a series of impulses to be conducted through the large fibers.

An alternative explanation for the ability of TENS to produce analgesia is based upon the premise that stimulation causes release of endorphins which subsequently attach to receptors and inhibit transmission of noxious stimuli. The neurophysiologic basic of this explanation rests on several pieces of evidence. First, opiate receptors have been identified in the substantia gelatinosa (the proposed site of the spinal gating mechanism) and in the periaqueductal gray matter of the brain (the proposed site of the central control trigger) (11). Second, Solomon et al (12), in looking at the effectiveness of TENS in decreasing postoperative pain and narcotic requirements, found that although TENS was effective in reducing pain and narcotic requirements in patients without a history of previous narcotic use, it was ineffective in patients with a history of narcotic use for a period greater than 2 months during the 6 months before surgery. These same patients also reported little or no relief from large amounts of narcotic analgesics. This suggests that the mechanism of action of electrical analgesia may involve the same neural substrate as narcotic-induced analgesia. This hypothesis may also explain why brief periods of stimulation can produce prolonged periods of pain relief. However, recent work by Abram et al (13) in patients with chronic pain fails to support this hypothesis. In their study, 15 patients who had been using transcutaneous electrical stimulation successfully for at least 1 month were given intravenous injections of naloxone (0.4 or 1.2 mg) or saline in a double-blind fashion in an attempt to reverse the stimulation-induced analgesia. No reversal of analgesia was seen after administration of naloxone or saline, suggesting that transcutaneous stimulation under the conditions used (low intensity 58 Hz stimulus) was not associated with release of endogenous opiates.

Melzack (14) recently offered a more generalized hypothesis to explain the analgesic effect produced by brief, intense peripheral stimulation. According to this theory, cells in the central gray matter have large receptive fields and complex projections. The arrival of peripheral impulses in this area results in perception of the stimulus but also activates inhibitory fibers in the brainstem which block painful stimuli from other body parts. Thus, TENS may activate inhibitory reflex areas in the brainstem.

Clinical Use of TENS

Regardless of the mechanism of action of TENS, TENS has assumed an important role in the management of chronic pain. More recently a number of investigators have studied the efficacy of TENS in the management of acute postoperative pain. The first
reported use of TENS for postoperative pain relief was by Hymes et al (15) in 1974. In this study, 115 patients were stimulated either continuously or intermittently for 4 of 5 days after surgery. Patients who were stimulated reported an 80% reduction in the intensity of pain. A curious exception was noted in patients having splenectomy or nephrectomy: only two of 16 patients reported pain relief following treatment. The authors also reported a significant decrease in the incidence of postoperative atelectasis and ileus as well as reduction of 1.5 days in the average length of stay in the postoperative intensive care unit. A major defect in this study was the authors’ choice of control patients. Although the control population did not differ in sex, age, type of surgery, or surgeons performing the procedure, control patients were chosen retrospectively from patients who had had operations 2.5 years before the onset of the study. This absence of concurrent control patients raised questions about the validity of the findings of the study, as well as the possibility that patients in the experimental group had a placebo response from the stimulator.

In a prospective, randomized controlled study by Cooperman et al (16), 50 patients had stimulators with or without current applied after upper abdominal surgery. If pain was not relieved by the stimulator, the patient was given 10 mg of diazepam. If this failed to provide adequate pain relief, 75 to 100 mg of meperidine was given. This procedure was repeated for 5 days each time the patient complained of pain. Good to excellent results (defined as a requirement of less than three doses of meperidine in 24 hours) were reported in 77% of patients with functioning stimulators. In contrast, only 33% of patients who had stimulators without current reported good to excellent results. Of patients with active stimulators 35% required no additional analgesia after surgery compared with 12% in the control group. There was, however, no difference between the two groups of patients in the incidence of postoperative atelectasis or pneumonia, in the duration of postoperative ileus, or in the length of stay in the postoperative intensive care unit. In addition, patients with malignant diseases did not respond as well to TENS as did patients with benign diseases, a finding that suggests that anxiety may play an important role in limiting the effectiveness of TENS.

Rosenberg et al (17) studied 12 patients who had cholecystectomy. Six of the 12 had TENS. Six control patients were given meperidine on demand, as were the patients given TENS. The results showed a 3-fold reduction in narcotic requirement in patients receiving TENS. Despite this difference, respiratory function as measured by arterial blood gas tensions, maximum expiratory flow rate, forced expiratory volume after 1 second, and vital capacity were not significantly different in the two groups. In addition, there was no difference in the incidence of postoperative atelectasis or the duration of ileus.

A number of studies show TENS to be effective in managing postoperative pain and reducing narcotic requirements. In a well controlled study by VanderArk and McGrath (18) TENS was found to be effective in alleviating acute postoperative pain in 67 patients in comparison with a control group of 39 patients who were given the same instructions before surgery but were given stimulators without batteries. Patients were stimulated or had placebo stimulation for 20 minutes three times per day until the day of discharge. In patients with functioning stimulators, 25% obtained complete relief of pain and required no narcotics after surgery, 52% obtained partial relief and required small doses of narcotics, and 23% had no relief. In contrast, only 17% of the control patients obtained partial relief whereas the remaining 83% obtained no relief. A small number of patients who were stimulated reported decreasing efficacy as the novelty of the therapy diminished, a finding that perhaps indicates a placebo effect.

A few remarks about the patients used in the control group in this study are pertinent. VanderArk and McGrath were the first investigators who advocated no battery or no current controls. The patients were informed that they might or might not perceive a tingling sensation in the area where the electrodes were in contact with the skin and were assured that pain medication would be available if the TENS did not relieve the pain. Although patients were not told to equate tingling with pain relief, it is certainly possible that the presence or absence of tingling could have affected the patient’s perception of the effectiveness of TENS. This same problem of finding suitable control patients in the study of TENS continues to trouble investigators. Melzack (14) has advocated using the placebo Venagus wave in control subjects. Subjects are told that they will receive a high frequency Venagus wave (named after the engineer who developed the equipment) which is known to abolish pain. All stimulating conditions are the same as those experienced by test subjects including wave forms on an oscilloscope and flashing lights on the stimulator. However, an open switch prevents any current from stimulating the subjects’ skin. The validity of no
battery or no current controls has yet to be determined, but, until a better method is found, it is likely that its use will continue.

Stabile and Mallory (19) used TENS for postoperative pain relief in a prospective, randomized study of patients undergoing total hip replacement or total knee replacement. Patients in this study were divided into three groups: group 1 consisted of 42 patients given hydromorphone intramuscularly for pain relief; group 2 consisted of 43 patients who received TENS plus hydromorphone on request; group 3 consisted of 22 patients who were given nerve stimulators without batteries plus hydromorphone on request. The results showed that patients in both groups 2 and 3 required significantly less postoperative narcotics than did patients in group 1 during the first three postoperative days. A positive placebo effect was noted in group 3, suggesting that the psychological benefits gained by allowing the patient to participate in his pain management and the relief of preexisting anxiety that results from exposure to electronic gadgetry which the patient believes will have an effect on postoperative pain may influence the patient's response to postoperative pain.

The use of TENS in the rehabilitation of patients is considered to be a major advance in the control of postoperative knee pain. Harvie (20) used TENS after surgery in 34 patients who had total knee replacements, synovectomies, meniscectomies, knee arthroscopy, patella plasties, or open reduction of fractures about the knee joint. Stimulation was applied as soon as the patient was fully recovered from the anesthetic and the patient controlled the unit for a period of 4 to 7 days. Quadriceps and range of motion exercises were also used. Electrode placement over the medial and collateral ligaments was found to produce a better response than electrodes placed on the medial sides of the incision. The decrease in the use of narcotics associated with TENS ranged from 75% to 100%. Five patients did not require any narcotics in the immediate postoperative period. When TENS was used, improvements were also noted in straight leg raising and range of motion exercises, together with a decrease in the length of hospital stay.

In a study of Pike (21), TENS was used for management of pain in 20 patients undergoing total hip replacement. The control group in this study received only narcotics for postoperative pain. The patients who were stimulated were also allowed to request 30 mg of meperidine on demand for pain. The stimulation was applied either intermittently or continuously and was discontinued 8 hours after surgery. Patients receiving TENS required 1.3 ± 1.38 (SD) doses of meperidine during the first 24 hours following surgery whereas control patients required 4.3 ± 2.05 doses. The difference was statistically significant.

In a study by Schuster and Infante (22), TENS was used in the management of postoperative pain for 72 hours following low back operations in 26 patients. The control group of 26 patients received only narcotics for postoperative pain. Patients receiving TENS also received narcotics on demand for pain. Patients in the TENS group required 4.65 ± 3.66 doses of narcotic compared with 10.92 ± 6.17 doses in the control group. The difference was statistically significant.

Finally, in a well controlled, prospective study by Ali et al (23), TENS was used in patients undergoing elective cholecystectomy. This study was designed to examine the efficacy of TENS in relieving postoperative pain and to evaluate the effect TENS had on postoperative pulmonary function. Patients with pulmonary disease were excluded from the study and apart from the use of TENS, postoperative care was standardized. All patients were required to do deep breathing, coughing, turning, and leg exercises; all patients were ambulated at 24 hours. Analgesia for the first 72 hours after surgery was restricted to meperidine, 1.5 mg/kg, on demand. The patients were divided into three groups: group 1 consisted of 15 patients who received TENS plus meperidine; group 2 consisted of 15 patients who received meperidine only; and group 3 consisted of 10 patients who received stimulators without current plus meperidine. Assessment of postoperative pulmonary function was done by measuring arterial PO2, vital capacity, and functional residual capacity 4 to 8 hours after surgery and again on postoperative days 1, 3, and 5. Patients receiving TENS required meperidine with a frequency of 4.7 ± 2.5 doses whereas those in groups 2 and 3 required 10.1 ± 2.7 and 10.4 ± 2.7 doses, respectively. Arterial PO2, vital capacity, and functional residual capacity decreased after surgery in all groups. In the TENS group, vital capacity decreased to 58.8% ± 10.6% of the preoperative value on the day of surgery whereas functional residual capacity decreased to 76.7% ± 12.3% and arterial PO2 to 93.1 ± 5.6% of preoperative values. All measurements in the TENS group improved in the postoperative period so that by day 5 the values had nearly returned to preoperative values. Corresponding changes in group 2 showed a decrease in vital capacity to 31.2% ± 5.9%, a decrease in functional residual capacity to 61.9% ± 13.4%, and a decrease in arterial PO2 to 78% ± 6.8% of preopera-
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the asymmetric wave form primarily because this
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psec. Below this range, the amplitude of the stimulat-
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chronic pain. There are no industry-wide standards,
however, and it is possible that some of the discrep-
ancies in the effectiveness of TENS noted in the
previously cited studies may be related to differences
in stimulator current properties.

In a study unrelated to postoperative pain relief, Perdkis (8) used TENS to treat 20 cases of protracted ileus resulting from abdominal surgery or trauma. Therapy was started 5 to 12 days after conservative treatment for ileus had failed. In 16 patients, ileus was completely relieved within 24 hours. Three cases did not improve with TENS therapy but were found to have mechanical obstruction at laparotomy. Because no control patients were used in this study, it is difficult to draw conclusions regarding the efficacy of treatment as the frequency with which ileus would have resolved spontaneously is unknown.

**Practical Considerations**

More than 200 companies in the United States now manufacture TENS devices for the relief of acute and chronic pain. There are no industry-wide standards, however, and it is possible that some of the discrepancies in the effectiveness of TENS noted in the previously cited studies may be related to differences in stimulator current properties.

Most stimulators in current clinical use deliver a balanced, biphasic potential in either a square or spiked wave form. Biphasic wave forms are used to prevent iontophoresis (i.e., transfer of ions from the skin to the TENS unit and vice versa). In addition, the wave forms may be either symmetrical or asymmetrical in configuration. Regardless of the configuration, it is important that the current be delivered equally in both phases of the wave to prevent electrolysis in the skin. Most commercially available TENS units utilize the asymmetric wave form primarily because this wave form has been found to be more acceptable to patients in terms of comfort and lack of muscle contractions (a nuisance commonly seen with symmetric wave forms at low stimulus frequencies).

The ideal pulse width is in the range of 60 to 150 \( \mu \)sec. Below this range, the amplitude of the stimulat-
anisms. Analgesic effects of low frequency, low intensity currents have not been reported and high frequency, high intensity stimulation is not tolerable to patients. As noted earlier, the analgesic effect of high frequency, low intensity TENS is not related to endorphin release as evidenced by the failure of naloxone to reverse TENS-induced analgesia (13).

Finally, electrode placement may also influence the efficacy of TENS. Harvie (20) has reported that placement of electrodes over the medial and collateral ligaments of the knee gave better results than placement on the sides of the incision. Mannheimer (26) suggests that multiple electrode placement in areas of diffuse pain or placement in a parallel or crossed pattern in a specific anatomic site may be most beneficial.

No complications have been observed from TENS when used properly, and the only morbidity has involved skin reactions at the electrode sites. Contraindications to the use of TENS include demand cardiac pacemakers and the first trimester of pregnancy (27).

Discussion

The use of TENS appears to offer a number of advantages in the treatment of postoperative pain. The problems of respiratory depression, sedation, orthostatic hypotension, and urinary retention seen with narcotics are avoided or reduced. The method is simple, noninvasive, nontoxic, and continuous. Physiologic or psychologic dependence does not develop with the use of TENS. There is a high level of patient acceptance and some physicians have noted that TENS enhances the physician-patient relationship by the extra concern for patient welfare and comfort that is shown when TENS is used.

The above studies indicate that TENS is often effective in relieving postoperative pain and reducing narcotic requirements. In a small number of patients, the need for narcotic analgesia is eliminated altogether. As noted by a number of observers, TENS appears to be most effective in relieving pain caused by trauma to muscles, bones, or peripheral nerves. Poorly localized visceral pain is less likely to respond. Psychological factors may play an important role in the response to TENS and briefing the patient before surgery on the potential value of TENS as a method of pain relief may improve the results. TENS is less effective in anxious or depressed patients. Although a placebo effect cannot be ruled out as playing a role in the effectiveness of TENS (19), the fact that patients who use stimulators without current require more narcotic after surgery suggests that TENS is acting through neurophysiologic processes.

An issue that has not been commented on by any of the previously mentioned investigators is the cost-effectiveness of TENS. In our institution, the initial charge to the patient for applying a stimulator is $27.00. This includes the fee of the therapist and the cost of the stimulating electrodes. Subsequent daily visits by a therapist for maintenance of the unit cost $4.00/day. Assuming use of the stimulator for 4 days, the total charge to the patient is $39.00. In contrast, 10 mg of morphine costs $0.46 and 100 mg of meperidine costs $0.62. Assuming six doses of narcotics per day, the cost of 4 days of narcotics is $11.04 and $14.88 for morphine and meperidine, respectively. Therefore, the use of TENS appears to be at least 3 to 4 times more costly than conventional therapy with narcotics in the management of postoperative pain. On the other hand, if TENS does decrease postoperative morbidity, as suggested by a number of authors, its use may actually decrease the overall cost of postoperative management, including a shorter duration of hospitalization. Just as important as the comparison of the costs of TENS and narcotic therapy is the question of which patients should use TENS. As alluded to earlier in this review, not all patients have significant pain after surgery. Should every patient receive TENS on completion of surgery or should its use be restricted to a more select population that has yet to be defined? Routine use of TENS would undoubtedly increase the cost of hospitalization which in certain cases might not be necessary as not all patients have severe enough postoperative pain to warrant the use of TENS. Enthusiasts of the use of TENS, however, frequently point to the claims made in the early work of Hymes et al (15) that TENS reduces the incidence of postoperative atelectasis, duration of ileus, and length of stay in a postoperative intensive care unit and that it should therefore reduce the cost of surgery and hospitalization. Subsequent studies by Cooperman et al (16) and Rosenberg et al (17) fail to support these claims. More recent work by Harvie (20) suggests, on the other hand, that for patients undergoing operations on the knee, TENS may be particularly indicated in view of the significant improvement in range of motion in the affected part and a decreased length of time spent in the hospital. Furthermore, Ali et al (23) suggest that TENS reduces postoperative pulmonary morbidity and improves postoperative pulmonary function by modifying the pain-induced depletions in vital capacity, functional residual capacity, and arterial oxygen tension.
Given this information and the problem of cost-effectiveness of a new treatment modality, which patients are most likely to benefit from TENS? The available data indicate that TENS is especially effective in modifying pain related to musculoskeletal trauma. Patients undergoing knee, hip, and low back surgery require less postoperative narcotics, are able to ambulate earlier with less pain, and may spend less time in the hospital. Although conflicting claims have been made, TENS appears to be effective in reducing the incidence of postoperative pulmonary complications in patients without preexisting lung disease. Whether TENS is equally useful in patients with chronic lung disease is a question that has yet to be answered, although, given the data by Ali et al (23) postoperative pulmonary function might be less adversely affected by TENS than by use of systemically administered narcotics. Another group of patients who might derive special potential benefit from the use of TENS are geriatric patients who are, in many cases, particularly sensitive to the side effects of depressant medications.

The use of TENS is attractive from the point of view that it not only has no known side effects but also that it is effective in the majority of patients in modifying or eliminating postoperative pain. As with all new modes of therapy, the cost of the devices used in TENS is high and, although we conclude that TENS is of considerable value in the reduction of postoperative pain and certainly deserves further clinical trials, it is currently only an adjunct to more classic pharmacologic methods of pain relief. In terms of patient acceptance, nursing care, and functional results, TENS has advantages over alternative analgesic regimens. Its future in the postoperative management of pain will depend, first, on establishment of its cost-effectiveness and, second, on more precise definition of exactly what types of patients will benefit more from TENS than from reliance on conventional pharmacologic means for the relief of postoperative pain.

With regard to technical standards and the electrical characteristics of the current that should be used in the treatment of postoperative pain, there is little agreement among the experts. Most of the investigators referred to in this article have used stimulator settings specified by the manufacturers of the respective units. In general, the most satisfactory results have been obtained utilizing stimulators that deliver a high frequency (50 to 100 Hz), low intensity (12 to 20 mamp at 1000 ohm) current with an asymmetric, biphasic wave form. These stimulators are comfortable to use and readily accepted by the patients. Although there is little specific information regarding which current parameters are most efficacious, most investigators agree on a positive outcome in the treatment of postoperative pain differing only on the frequency and duration of success. This fact suggests that the different current characteristics associated with various commercially available stimulators are important only in that they should fall within the general guidelines mentioned above in order to obtain a reasonable rate of success. Any further recommendations regarding the technical aspects of TENS current must await future studies looking specifically at various frequencies, wave forms, and current intensities.

REFERENCES
Reduced Stress Response with Pulsatile Flow during Cardiopulmonary Bypass

The effect of pulsatile flow during cardiopulmonary bypass on the hormonal stress response was studied in 26 patients. Thirteen patients had "routine" bypass and 13 had pulsatile bypass with an average pulse pressure of 30 mm Hg. Plasma vasopressin levels were significantly elevated during bypass in both groups, but were lower with pulsation (66 ± 11 vs 36.3 pg/ml, p < 0.05). Epinephrine levels increased in both groups during bypass, but were higher after bypass (1179 ± 448 vs 713 ± 140 pg/ml, p < 0.05) and in the recovery room (1428 ± 428 vs 699 ± 155 pg/ml, p < 0.05) in the nonpulsatile groups. The same response was noted in norepinephrine levels (924 ± 225 vs 465 ± 90 pg/ml, p < 0.05; 1915 ± 491 vs 717 ± 112 pg/ml, p < 0.05). There was no significant changes in renin activity in either group, but the increase after cardiopulmonary bypass was greater in the nonpulsatile group (2.0 ± 0.7 vs 1.36 ± 0.4 ng/ml/hr, NS). These data suggest that pulsatile flow significantly attenuates the vasopressin and catecholamine stress response to cardiopulmonary bypass. This may explain the increased flow requirements and better tissue perfusion and organ function and the decreased incidence of postoperative hypertension after bypass using pulsatile flow. (Philbin DM, Levine FH, Kono K, et al. Attenuation of the stress response to cardiopulmonary bypass by the addition of pulsatile flow. Circulation 1981;64:808-12)