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Comparison of Continuous and Intermittent Transcutaneous Electrical Nerve Stimulation in Postoperative Pain Management after Coronary Artery Bypass Grafting: A Randomized, Placebo-Controlled Prospective Study

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ABSTRACT

Objective: We compared the effectiveness of continuous transcutaneous electrical nerve stimulation (TENS) and intermittent TENS in the management of pain after coronary artery bypass grafting (CABG).

Methods: We randomized 100 patients who had undergone median sternotomy for CABG into 4 groups with 25 patients each: (1) continuous TENS (CTENS) and pharmacologic analgesia, (2) intermittent TENS (ITENS) and pharmacologic analgesia, (3) placebo TENS (PTENS) and pharmacologic analgesia, and (4) pharmacologic analgesia alone (control). We studied these groups with regard to the relief of postoperative pain during the first 24 hours. For each patient we recorded the following: demographic characteristics; vital signs; intensity of pain with a visual analogue scale (VAS) before treatment (VAS_0), at the 12th hour (VAS_{12}), and at the 24th hour (VAS_{24}); and analgesic intake.

Results: The groups were comparable with respect to age, sex, and body mass index at baseline. Mean VAS scores decreased within each group; however, the mean VAS_{12} and VAS_{24} scores decreased significantly in the CTENS and ITENS groups, compared with PTENS and control groups ($P < .05$). We found no significant difference between the CTENS and ITENS groups with respect to decreasing VAS_{12} and VAS_{24} scores ($P > .05$). Narcotic intake was significantly less in the CTENS and ITENS groups than in the control and PTENS groups ($P < .01$). Furthermore, narcotic requirements were significantly lower in the CTENS group than in the ITENS group ($P < .01$).

Conclusions: CTENS and ITENS after median sternotomy for CABG decreased pain and reduced narcotic requirements more than in the PTENS and control treatments during first postoperative 24 hours. Neither CTENS nor ITENS is superior to the other in decreasing pain; however, CTENS leads to a greater reduction in the narcotic requirement than ITENS.

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INTRODUCTION

Patients undergoing coronary artery bypass grafting (CABG) experience considerable early postoperative chest pain [Fitzpatrick 1988]. Pain has a first-degree role in the development of many complex physiological events during the postoperative period. Undertreated postoperative pain produces a number of adverse effects, including impaired pulmonary function [Filos 1999]. Postoperative pain is also a potent trigger for the stress response, activating the autonomic nervous system and causing adverse effects on multiple organ systems [Pasero 1999]. Pain may inhibit effective coughing, deep breathing, and restrict early postoperative mobilization [Chulay 1982]. Consequently, lung ventilation and independence in self-care may not be optimal, and there may be a tendency toward lung infection [Jenkins 1989]. Improved management of postoperative pain has been shown to reduce the overall postoperative complication rate, the incidence of cardiovascular failure, and major infectious complications [Yeager 1987]. Furthermore, pulmonary exercises have great importance in decreasing pulmonary complications after open heart surgery. Therefore, the pain that limits pulmonary exercises should be decreased.

Invasive and noninvasive interventions are applied in postoperative pain management. Among the invasive techniques, epidural catheterization, local regional blockage, and use of intravascular narcotic medicines are the most commonly applied techniques [Konstantatos 2008]. The most preferred noninvasive techniques are oral or transdermal narcotic and/or nonsteroidal anti-inflammatory drug (NSAID) use. Each of these techniques has specific side effects and limitations [Konstantatos 2008].

Transcutaneous electrical nerve stimulation (TENS) is a noninvasive technique that is effective in postoperative pain management [Forster 1994; Solak 2007]. It has no side effects, in contrast to the methods mentioned above; however, it is still not widely used in postoperative pain management and its effect in relation to its application period is controversial.

The aim of this study was to compare continuous TENS (CTENS), intermittent TENS (ITENS), placebo TENS (PTENS), and control treatments with respect to 5 criteria: (1) pain, (2) intake of narcotic medication, (3) forced vital capacity (FVC), (4) forced expiratory volume in 1 second

(FEV_1), and (5) incidence of pulmonary atelectasis during the first 24 hours after median sternotomy for CABG surgery.

MATERIALS AND METHODS

We included in the study 100 patients who had undergone median sternotomy for CABG with a unilateral left internal mammarian artery or saphenous vein. A table of random numbers was used to randomized patients to (1) CTENS and pharmacologic analgesia, (2) ITENS and pharmacologic analgesia, (3) PTENS and pharmacologic analgesia, or (4) pharmacologic analgesia alone (control) to relieve postoperative pain during the first 24 hours following median sternotomy. There were 25 patients in each group.

The patients had no other cardiac abnormalities or conditions that required additional surgery at the time of CABG. Patients with a history of narcotic abuse or extreme sensitivity to opioid-related side effects, previous experience with TENS therapy, or with clinically significant cardiovascular, pulmonary, renal, hepatic, or neurologic disease were excluded from participating in this study. All patients gave informed signed consent; the study protocol was approved by our Institutional Research Ethics Committee.

A Biomed Plus (BioMedical Life Systems, Vista, CA, USA) TENS unit was used. The TENS unit provided an asymmetric square biphasic waveform at a frequency of 100 pulses/s and a pulse width of 100 microseconds.

In the CTENS group, TENS was used continuously in the first 24-hour postoperative period. Two sterile electrodes (first-unit channel) were placed on one side of the incision, and 2 other electrodes (second-unit channel) were placed on the other side. The electrodes (5 × 5 cm) were positioned 1 cm away from the suture line. The stimulus intensity was adjusted until a strong but comfortable tingling sensation was felt.

In the ITENS group, electrical stimulation for 1 hour was followed by a 1-hour rest interval; the 1-hour stimulation was then performed again. The stimulus intensity was adjusted until a strong but comfortable tingling sensation was felt.

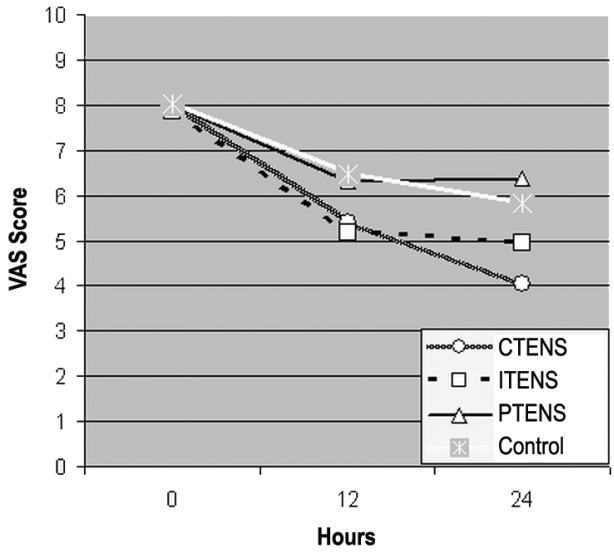

Figure 1. Changes in the visual analogue scale (VAS) score in the continuous (CTENS), intermittent (ITENS), and placebo (PTENS) transcutaneous electrical nerve stimulation groups and in the control group during the first 24 hours postoperatively.

In the PTENS group, the PTENS unit was identical to the treatment unit but did not provide current. The PTENS group was told that the electrical stimulation was silent and produced no sensation. Placebo stimulation was instituted continuously for 24 hours postoperatively.

In the control group, the patients received only patient-controlled analgesia (PCA).

Metamizole sodium (500 mg intramuscularly) was administered to all patients in all groups during the 24-hour period.

Table 1. Demographic and Operative Data for the Patients*

	CTENS (n = 25)	ITENS (n = 25)	Control (n = 25)	PTENS (n = 25)	*P*
Age, y	64.5 ± 6.93	67.8 ± 8.6	64.9 ± 7.3	65.0 ± 6.4	NS
Male/female sex, n	22/3	21/4	23/2	21/4	NS
Body mass index, kg/m^2	26.1 ± 1.2	25.9 ± 1.6	26.4 ± 1.4	26.0 ± 1.1	NS
Diabetes mellitus, n (%)	4 (16)	5 (20)	5 (20)	4 (16)	NS
Hypertension, n (%)	7 (28)	8 (32)	7 (28)	8 (32)	NS
COPD, n (%)	5 (20)	6 (24)	7 (28)	5 (20)	NS
Operation time, min	157.3 ± 37.8	154.1 ± 36.9	153.5 ± 37.5	157.9 ± 39.5	NS
Extubation time, h	8.4 ± 2.9	8.5 ± 3.2	8.0 ± 3.7	8.5 ± 2.5	NS
ICU stay, h	19.5 ± 2.9	19.6 ± 2.9	19.4 ± 2.9	19.5 ± 2.9	NS
Hospital stay, d	6.2 ± 0.7	5.2 ± 0.6	6.0 ± 0.8	6.3 ± 0.8	NS

*Data are presented as the mean ± SD where indicated. CTENS indicates continuous transcutaneous electrical nerve stimulation (TENS); ITENS, intermittent TENS; PTENS, placebo TENS; NS, not statistically significant; COPD, chronic obstructive pulmonary disease; ICU, intensive care unit.

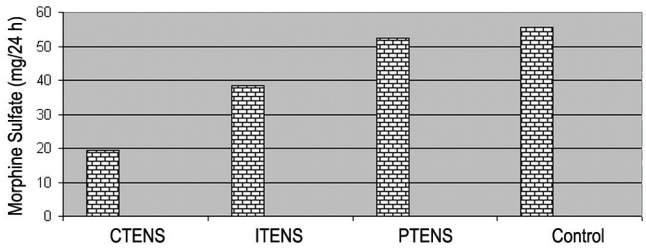

Figure 2. Narcotic intake in the continuous (CTENS), intermittent (ITENS), and placebo (PTENS) transcutaneous electrical nerve stimulation groups and in the control group during the first 24 hours postoperatively.

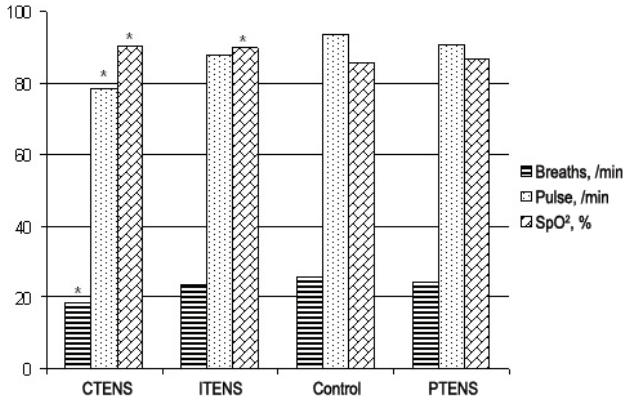

Figure 3. Mean breaths per minute, pulses per minute, and arterial oxygen saturation of hemoglobin (SpO_2) in the continuous (CTENS), intermittent (ITENS), and placebo (PTENS) transcutaneous electrical nerve stimulation groups and in the control group during the first 24 hours postoperatively. Statistically significant differences are indicated (*).

All patients received a PCA device containing a standardized solution of morphine sulfate (1 mg/mL). The operational aspects of the PCA device (LifeCare® PCA Plus II Infuser; Abbott Laboratories, North Chicago, IL, USA) was connected to the patient's intravenous line and programmed to deliver 40-µg/kg bolus doses of morphine sulfate (2-5 mg) on demand, with a minimal lockout interval of 10 minutes and a maximal hourly dose of 6-15 mg. Supplemental 80-µg/kg bolus doses of morphine sulfate (5-l0 mg) were administered intramuscularly if the patient was unable to achieve adequate pain relief from the PCA device.

The intensity of pain was assessed by means of a visual analogue scale (VAS) from 0 (no pain) to 10 (unbearable pain) before treatment (VAS_0), on the 12th hour of treatment (VAS_{12}), and on the 24th hour of treatment (VAS_{24}) [Chapman 2001].

Age, sex, body mass index, systemic disease, length of operation time, length of extubation time, length of intensive care unit stay, and length of hospital stay were recorded for each patient.

Table 2. Vital Signs of the Patients*

	CTENS (n = 25)	ITENS (n = 25)	Control (n = 25)	PTENS (n = 25)	*P*
Breaths, /min	18.6 ± 2.4	23.5 ± 2.6	25.7 ± 2.9	24.3 ± 3.5	.001
Pulse rate, /min	78.3 ± 5.2	87.8 ± 7.7	93.4 ± 11.9	90.7 ± 12.7	.001
TA (systolic), mm Hg	113.1 ± 12.6	115.3 ± 14.6	123.6 ± 15.9	120.4 ± 15.0	NS
TA (diastolic), mm Hg	69.2 ± 5.9	69.8 ± 6.3	76.1 ± 6.8	74.5 ± 8.5	NS
FEV_1, %					
Preoperative	83.2 ± 9.1	83.1 ± 8.9	84.8 ± 9.9	83.3 ± 9.0	NS
Postoperative	47.5 ± 5.6	41.9 ± 7.6	39.9 ± 8.3	39.5 ± 8.0	.002
FVC, L					
Preoperative	2.9 ± 0.5	2.9 ± 0.5	3.0 ± 0.5	3.0 ± 0.5	NS
Postoperative	1.9 ± 0.2	1.8 ± 0.2	1.6 ± 0.3	1.6 ± 0.4	.001
SpO_2, %	90.5 ± 2.8	89.8 ± 3.2	85.3 ± 4.9	86.6 ± 5.1	.001
pH	7.4 ± 0.04	7.4 ± 0.07	7.4 ± 0.06	7.4 ± 0.07	NS
PaO_2, mm Hg	56.8 ± 8.2	59.2 ± 5.3	55.7 ± 6.5	56.0 ± 6.4	NS
$PaCO_2$, mm Hg	29.5 ± 3.3	29.2 ± 4.4	30.5 ± 4.4	29.4 ± 4.4	NS
HCO_3^-, mmol/L	24.5 ± 2.7	23.8 ± 3.2	24.2 ± 3.1	24.2 ± 3.3	NS
LIMA, n (%)	23 (92)	24 (96)	22 (88)	23 (92)	NS
Body temperature, n (%)	6 (24)	10 (40)	22 (88)	12 (48)	.014

*Data are presented as the mean ± SD where indicated. CTENS indicates continuous transcutaneous electrical nerve stimulation (TENS); ITENS, intermittent TENS; PTENS, placebo TENS; TA, tension, arterial; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; SpO_2, arterial oxygen saturation of hemoglobin; PaO_2, partial pressure of oxygen, arterial; $PaCO_2$, partial pressure of carbon dioxide, arterial; LIMA, left internal mammarian artery.

The intensity of pain, analgesic intake, pulse rate, arterial tension (TA), breaths per minute, body temperature, arterial oxygen saturation of hemoglobin (SpO_2), partial arterial oxygen pressure (PaO_2), partial arterial carbon dioxide pressure ($PaCO_2$), pH, HCO_3^-, FEV_1, FVC, and pulmonary complications were recorded during the first 24 hours after median sternotomy.

A chest radiograph (CXR) was taken on the 24th hour postoperatively, and the same radiologist assessed all CXRs for atelectasis.

Statistical Analysis

Statistical calculations were performed with SPSS 11.5 (SPSS, Chicago, IL, USA). The Kruskal-Wallis test was used for intergroup comparisons, and the paired-sample test was used for intragroup evaluations of therapeutic effectiveness. The chi-square test was used to evaluate postoperative complications. *P* values <.05 were considered statistically significant.

RESULTS

Table 1 summarizes the demographic characteristics, systemic diseases, operation times, extubation times, and the lengths of the intensive care unit and hospital stays of the patients. The groups were comparable with respect to age, sex, and body mass index at baseline.

Postoperative Pain

The mean (±SD) VAS_0 scores for the CTENS, ITENS, control, and PTENS groups were 8.1 ± 1.1, 7.9 ± 1.0, 8.0 ± 1.0, and 8.0 ± 1.0 ($P > .05$), respectively. The corresponding mean VAS_{12} scores were 5.4 ± 1.1, 5.2 ± 1.6, 6.5 ± 1.4, and 6.3 ± 1.9 ($P < .05$), and the corresponding mean VAS_{24} scores were 4.1 ± 0.8, 4.9 ± 1.5, 5.8 ± 1.6, and 6.4 ± 1.5 ($P < .05$) (Figure 1). The mean VAS scores decreased within each group; however, the mean VAS_{12} and VAS_{24} scores decreased significantly in the CTENS and ITENS groups, compared with the PTENS and control groups ($P < .05$). On the other hand, no significant difference ($P > .05$) was found between the CTENS and ITENS groups with respect to decreasing VAS_{12} and VAS_{24} scores.

Narcotic Intake

The mean morphine sulfate doses administered during the postoperative 24-hour period were 19.5 ± 7.7 mg, 38.5 ± 12.3 mg, 55.5 ± 9.3 mg, and 52.3 ± 8.4 mg in the CTENS, ITENS, control, and PTENS groups, respectively (Figure 2). Narcotic intake was significantly less in the CTENS and ITENS groups than in the control and PTENS groups ($P < .01$). Furthermore, the narcotic requirement was significantly lower in the CTENS group than in the ITENS group ($P < .01$). There was no difference between the control and PTENS groups with respect to narcotic intake ($P > .05$).

Pulmonary Function

Table 2 summarizes the vital signs (such as breaths per minute, pulses per minute, TA, body temperature, SpO_2, PaO_2, $PaCO_2$, pH, HCO_3^-, FEV_1, and FVC) of the patients. The mean number of breaths per minute and the mean pulses per minute were significantly lower in the CTENS group during the 24-hour postoperative period. The mean SpO_2 was significantly higher in the CTENS and ITENS groups during the 24-hour postoperative period (Figure 3).

FEV_1 values decreased significantly ($P < .05$) within each group at postoperative hour 24 (Table 2). The postoperative FEV1 result was highest in the CTENS group ($P < .05$).

FVC values decreased significantly ($P < .05$) within each group at postoperative hour 24 (Table 2). The postoperative FVC result was highest in the CTENS group ($P < .05$).

Atelectasis in CXR

No atelectasis was apparent in the anteroposterior CXRs performed on the 24th hour in CTENS and ITENS groups, but atelectasis was observed in 6 patients (24%) in the control group and in 2 patients (8%) in the PTENS group ($P < .05$). All of the atelectases were segmental and improved without a bronchoscopy requirement.

DISCUSSION

We report that CTENS and ITENS after median sternotomy for CABG decreases pain and reduces narcotic requirements more than PTENS and control treatments during the first 24-hour postoperative period. Furthermore, neither CTENS nor ITENS is superior to the other in decreasing pain; however, CTENS treatment decreases the narcotic requirement more than ITENS treatment.

To our knowledge, this randomized placebo-controlled study is the first to compare the effect of CTENS and ITENS on pain after median sternotomy for CABG surgery; however, there are studies that have investigated the effect of CTENS or ITENS alone on postoperative pain. In the current study, we confirmed the previous reports that CTENS and ITENS are effective and well tolerated in the control of postoperative pain [Rooney 1986; Bayindir 1991; Erdogan 2005; Solak 2007; Cipriano 2008; Emmiler 2008]. Cipriano et al [2008] evaluated the effectiveness of CTENS for treatment of postoperative pain after cardiac surgery and found that TENS was significantly effective in reducing postoperative pain compared with a sham treatment. In another study, we demonstrated that ITENS was more effective than PTENS or control treatments in decreasing pain and limiting opioid and nonopioid medication intake during the first 24-hour period following median sternotomy [Emmiler 2008]. Erdogan et al [2005] found that CTENS applied for 48 hours following thoracotomy was beneficial for pain relief.

Opioids are one of the most popular analgesic agents used in patients after cardiac surgery [Konstantatos 2008]; however, determining the minimum effective analgesic concentration is a difficult task. In addition, opioids may lead to cough suppression and limit effective expectoration, and opioids are associated with many side effects, including respiratory depression, nausea, sedation, urinary retention, constipation, and vomiting [Locicero 2005]. There is a trend toward using alternative pain-management modalities for postoperative

pain [Erdogan 2005; Solak 2007]. In the current study, we observed that CTENS and ITENS decreased narcotic intake significantly. Furthermore, the need for narcotic was the least in the CTENS group, a finding that was statistically significant. Erdogan et al [2005] found that CTENS applied for 48 hours following thoracotomy decreased the need for opioids. Solak et al [2007] reported that ITENS used for postthoracotomy pain reduced narcotic and NSAID requirements. VanderArk and McGrath [1975] showed that analgesia could be achieved and narcotic requirements could be decreased in patients who underwent abdominal or thoracic procedures when TENS was applied on an intermittent basis after the pain occurred. Soloman et al [1980] demonstrated that patients undergoing hip arthroplasty, transabdominal gynecologic procedures, or lumbar spine surgery achieved a significant reduction in postoperative narcotic use while receiving CTENS therapy.

We observed that FEV_1 and FVC values were highest in the CTENS group at postoperative hour 24. Whether TENS therapy attenuates the usual postoperative decrement in pulmonary function is controversial. Cipriano et al [2008] observed improvement in chest wall–pulmonary mechanics after TENS, with proportional increases in tidal volume and vital capacity, following cardiac surgery. Erdogan et al [2005] showed that TENS caused increases in spirometric respiratory function test values (FEV_1 and FVC). Stratton and Smith [1980] applied TENS therapy after pain was present on the second postoperative day in patients who had undergone thoracotomy and found that the FVC improved after 10 minutes of TENS therapy; the control group did not receive a sham stimulator therapy, however. In a sham-controlled study of TENS therapy in patients who underwent cholecystectomy, Ali et al [1981] demonstrated that the postoperative decrease in functional residual capacity, vital capacity, and arterial PO_2 was present but significantly less than in the control groups.

Atelectasis is one of the most common postoperative complications. If the pain that occurs after median sternotomy and thoracotomy is not treated properly, it limits deep inspiration, effective coughing, and expectoration of secretions [Chulay 1982]. In our study, we observed no atelectases in the CTENS and ITENS groups in the CXRs obtained at postoperative hour 24, but atelectasis did occur in 6 patients in the control group and in 2 patients in the PTENS group. Additional benefits that have been attributed to TENS therapy include a decrease in the occurrence of postoperative atelectasis and pneumonia in patients who have undergone cholecystectomy [Ali 1981] or various intra-abdominal procedures [Hymes 1974].

The groups did not differ with respect to the lengths of hospital and intensive care unit stays. Our finding was consistent with other studies that demonstrated no benefit from TENS therapy with respect to length of hospital stay [Schomburg 1983] and the length of intensive care unit stay [Cooperman 1977].

In conclusion, TENS is a noninvasive and successful treatment modality in the management of postoperative pain after median sternotomy for CABG. There is no difference between CTENS and ITENS therapies with respect to decreasing postoperative pain; however, narcotic intake is less with CTENS therapy than with ITENS therapy. Further studies with large sample sizes and long follow-up periods are needed to confirm our results.

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