Effect of TENS on Pain, Medications, and Pulmonary Function Following Coronary Artery Bypass Graft Surgery*

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The efficacy of transcutaneous electrical nerve stimulation (TENS) as an adjunct to narcotic medications for the management of postoperative pain was assessed in a prospective, randomized, controlled study of patients following coronary artery bypass graft (CABG) surgery with the right or left internal thoracic artery (ITA). Forty-five male patients (mean age, 57 ± 6 years) were randomly assigned to (1) TENS, (2) placebo TENS, or (3) control treatments (n=15 each), following extubation and during the 24- to 72-h postoperative period. Two-way analysis of variance tests indicated no significant differences among treatment groups for (1) pain with cough, (2) narcotic medication intake, (3) FVC, (4) FEV1, and (5) PEFR (p>0.05). However, pain at rest reported by the TENS group was significantly lower than that reported by the control group (treatment main effect; p<0.04), although no significant differences were observed between the TENS and placebo or between the placebo and control groups (p>0.05). All six criterion measures were characterized by significant changes over time for the entire group (n=45; time main effect; p<0.01), as follows: pain and medication intake were similar on days 1 and 2, but were significantly less on day 3, and pulmonary functions were significantly lower than preoperatively on day 1, decreased further on day 2, and despite an improvement on day 3, remained significantly lower than preoperative values (p<0.01). This study suggests that the addition of TENS, applied continuously during the immediate postoperative period following CABG with ITA, may not be advantageous in pain management or the prevention of pulmonary dysfunction. (Chest 1994; 106:3143-49)

Patients who have undergone coronary artery bypass graft surgery (CABG) report considerable early postoperative chest pain, particularly if one or both of the internal thoracic arteries (ITA) have been used for grafting. Pain may inhibit effective coughing, deep breathing, and restrict early postoperative mobilization. As a result, lung ventilation and independence in self-care may not be optimal, and there may be a tendency toward lung infection. Narcotic medications, although valuable for pain control, have been associated with the undesired side effects of respiratory depression, drowsiness, nausea, and vomiting. For these reasons, adjunctive means of pain control that may help limit narcotic medication intake and reduce opiate side effects are of considerable interest.

Transcutaneous electrical nerve stimulation (TENS) has been reported to be an effective adjunct to traditional pain medications following cardiac surgery. In a descriptive study, Klin et al used TENS as an adjunct to narcotics on days 3 and 4 after cardiac surgery. However pain levels, medication amounts, pulmonary functions, and statistical analyses were not described. Navarathnam et al used TENS for 72 h after CABG, valve repair, and other cardiac procedures, with treatment and placebo groups, and recorded medications and pulmonary function test (PFT) results daily. Bayindir et al used TENS for 180 min, starting at 4 ± 1.5 h after surgery, after cardiac valve repair and CABG without ITA, with treatment and placebo groups. Both Navaratham et al and Bayindir et al used TENS as the initial therapy for postoperative pain, with pain medication provided if TENS was ineffective.

Typically, TENS is used as an adjunct to postoperative medications, rather than as the first or only pain control system. Patients are usually heavily sedated by large doses of narcotics during the first 12 h after cardiac surgery, and may be unable to respond appropriately to assessment procedures during this time. Furthermore, measurement of pain at rest may not reflect the total extent of the pain experienced by patients, as it does not assess the pain associated with the coughing and deep breathing exercises uni-

Key words: coronary surgery; pain; pulmonary function; TENS

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ANOVA=analysis of variance; CABG=coronary artery bypass graft; FEV1=forced expiratory volume in 1 s; FVC=forced vital capacity; ITA=internal thoracic artery; PEFR=peak expiratory flow rate; PFT=pulmonary function tests; TENS=transcutaneous electrical nerve stimulation
versally used in postoperative rehabilitation programs. 12,13

The purpose of this study was to compare TENS, placebo TENS, and control treatments on six criterion measurements: (1) intake of narcotic medication; (2) pain at rest; (3) pain with cough; (4) forced vital capacity (FVC); (5) forced expiratory volume in 1 s (FEV1); and (6) peak expiratory flow rate (PEFR), during a 48-h period (days 1 to 3) following CABG surgery.

METHODS

Subjects

This study was approved by the University of Western Ontario Review Board for Health Sciences Research Involving Human Subjects. Sixty male patients admitted to the University Hospital (London, Ontario, Canada) for CABG were randomly assigned preoperatively to one of three treatment groups: (1) TENS; (2) placebo TENS; and (3) control. The patients had no other cardiac abnormalities or conditions that required additional surgery at the time of CABG. All patients were administered a fentanyl or sufentanil-based general anesthetic, and underwent standard CABG of one or more coronary arteries, using either the left or right ITA, and the saphenous vein as required.

Pain at rest and pain with cough were considered to be the primary variables of interest in the present study. Sample size estimation was based on the assumption that a 2.5-point difference between treatment groups on the verbal numerical pain scale would be clinically significant. Assuming a standard deviation of 2.25 points, an alpha of 0.05, and a beta of 0.20 (power of 0.80), sample size was estimated at 14 patients per group.14 To account for losses, 20 patients were entered into each group presurgery.

Criterion Measurements

Six outcome measures were studied: (1) pain at rest; (2) pain with cough; (3) intake of narcotic medication; (4) FVC; (5) FEV1; and (6) PEFR. The first postoperative tests were performed after the patient was extubated, about 24 h after surgery. Subsequent measurements were repeated at the same time each day, during the next 2 days until 72 h postoperatively. All measurements were determined by a single physical therapist who specialized in cardiovascular therapy (E.L.F.).

All patients were given intravenous or intramuscular morphine on the first and second postoperative days (prescribed at doses of 2 to 4 mg/15 min intravenously or 2 to 10 mg/3 to 4 h intramuscularly) and were prescribed acetaminophen with 30 mg of codeine (one to two tablets every 3 to 4 h) on the second day. Postoperative narcotic medications were provided as deemed appropriate by the medical staff, regardless of the patient’s treatment group assignment. Medication intake was determined as the amount of morphine equivalents per 24 h.15,16 Patients quantified their median sternotomy incision pain using a verbal numerical pain scale from “0” (no pain whatsoever) to “10” (the worst imaginable pain).17-19 At each test, the patient was first asked to quantify his pain at rest while in bed. Subsequently, while sitting at the bedside, they were asked to perform PTETs, to cough strongly and effectively a few times, and then to quantify chest incision pain with reference to coughing.

Pulmonary function tests (FVC, FEV1, and PEFR) were performed (using a Respiradyn II Pulmonary Function/Ventilation Monitor, Sherwood Medical Company, St. Louis). The best of three efforts, completed with the patient sitting on the edge of the bed, was used for analysis. The pulmonary function results were expressed as a percent of predicted value.20,21

Treatments

The TENS units (Nuwave Staodyn, Stadynamics, Longmont, Colo) provided a symmetrical, rectangular, biphasic waveform with zero net DC current, 278 pulses per second frequency, 60-µs pulse width (phase duration), and 1,800-µs interphase interval/duration. The placebo TENS units appeared identical to the treatment TENS units, including operating indicator lights and batteries, but did not provide current. After the first postoperative measurements were taken, the TENS and placebo TENS groups were set up with their TENS units. Two standard sterile disposable electrodes (18x5.5 cm) with karaya gum backing were placed on the skin either on the side of the incision approximately 2 cm away from the suture line. The standard incision dressing was not disturbed. The leads exited from the cranial end of the electrodes. Two identical electrodes were placed on either side of the spinous processes in the paravertebral area from T1 to T5. Both sets of electrodes were controlled by the same intensity control dial. The TENS units were clipped directly to the patient’s gown or placed in a small cloth bag (about 14 cm x 8 cm bag) pinned onto the gown of the patient or hung around his neck.

Prior to turning on the TENS units to the constant mode setting, patients in both TENS groups were reminded that they may or may not feel the sensation of the TENS current, with the explanation that the body accommodates to TENS, making the sensation difficult to feel after a short period of time. All patients had been advised that all three treatment groups were equally important in determining the effectiveness of TENS and that the most effective treatment could not be predicted. The TENS group adjusted their electrical stimulation to the clinically accepted norm of a strong, but comfortable tingling sensation,10,15,22 and were instructed to maintain it at this level by adjusting the intensity control themselves.12 The placebo TENS group received identical instructions and were requested to do similarly, even if they were not sure if they were feeling any electrical current at the time. The stimulators were to be maintained at these levels by the patients for the entire study for both groups, day and night, with 2-h checks by nursing staff.

Most patients were transferred from the intensive care unit to the cardiovascular surgery ward by approximately 48 h after the surgery. The end point of the study was at 72 h after surgery, a time when clinically most patients experienced much less pain, were able to walk and mobilize independently, and were not requesting pain medication as frequently. The TENS units were removed at the end of the study unless a patient requested continued use of TENS.

Statistical Analysis

One-way analysis of variance (ANOVA) tests were used to compare the three treatment groups on the descriptive variables. A two-way ANOVA (treatments by times of measurement) was used to examine each of the six criterion measurements, individually.23 Following significant F ratios, a Newman-Keuls post hoc test was used to compare selected pairs of means.24 A p value ≤ 0.05 was deemed statistically significant.

RESULTS

Of the original 60 patients, five in each treatment group did not complete the study, resulting in 15 patients in each group. Two patients died, nine were withdrawn due to postoperative complications that required discontinuation of TENS or placebo TENS for more than 60 min at one time, and four requested discontinuation (see Table 1 for descriptive information). Although 76 percent of the final sample had a history of smoking cigarettes, only 18 percent con-
continued to smoke within 6 weeks of surgery: two in the TENS group and three in each of the placebo and control groups.

On the ANOVAs for descriptive measures (Table 1), both age and weight were characterized by significant F ratios (p<0.05). For age, the placebo group was significantly older than was the control group (p<0.01). For weight, the placebo group weighed significantly less than the TENS group (p<0.05). All other ANOVAs were nonsignificant (p>0.05).

No significant treatment group by time interaction was observed in any of the six ANOVAs (p>0.05) (Figs 1 and 2). In five of the ANOVAs, the three treatment groups were similar (p>0.05)—when scores were averaged over the times of measurement (treatment main effect). The single exception to this pattern was pain at rest (treatment main effect; p<0.04); the TENS group reported significantly less pain than did the control group (p<0.05), although no significant differences were observed in the pain at rest reported by the TENS and placebo TENS groups or between the placebo TENS and control groups (p<0.05).

All six ANOVAs indicated significant changes over time for the entire group of patients (n=45) (time main effect; p<0.01). Narcotic medications, pain at rest, and pain with cough were similar on days 1 and 2 (p>0.05), but significantly lower on day 3 than on either day 1 or 2 (Fig 1; p<0.05). The pulmonary function measures displayed similar patterns to one another—scores were significantly lower postoperatively than preoperatively (p<0.01), with scores on day 2 being the lowest and those on day 3 being the highest postoperatively (Fig 2). More specifically, FVC on day 1 was significantly higher than on day 2, but not significantly different from day 3 (p>0.05), while FEV₁ on day 2 was significantly lower than on day 3 (p<0.01). The PEFR on day 1 was not significantly different from

![Graph 1](image1.png)

**Table 1—Patient Descriptive Information, Preoperative Pulmonary Function, and Surgical Parameters**

<table>
<thead>
<tr>
<th>Variable</th>
<th>TENS (n=15)</th>
<th>Placebo TENS (n=15)</th>
<th>Control (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>58.7 (8.1)</td>
<td>61.7 (6.6)</td>
<td>54.7 (8.0)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>176.1 (5.3)</td>
<td>173.6 (5.4)</td>
<td>173.5 (6.8)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>86.0 (8.8)</td>
<td>77.1 (9.2)</td>
<td>83.3 (9.0)</td>
</tr>
<tr>
<td>% predicted FVC</td>
<td>91 (11)</td>
<td>88 (17)</td>
<td>92 (14)</td>
</tr>
<tr>
<td>% predicted FEV₁</td>
<td>88 (14)</td>
<td>88 (18)</td>
<td>89 (17)</td>
</tr>
<tr>
<td>% predicted PEFR</td>
<td>73 (28)</td>
<td>72 (40)</td>
<td>75 (24)</td>
</tr>
<tr>
<td>CABG grafts†</td>
<td>2.7 (0.6)</td>
<td>2.9 (0.7)</td>
<td>3.3 (0.8)</td>
</tr>
<tr>
<td>Left ITA</td>
<td>15/15</td>
<td>14/15</td>
<td>14/15</td>
</tr>
<tr>
<td>Right ITA</td>
<td>0/15</td>
<td>0/15</td>
<td>1/15</td>
</tr>
<tr>
<td>Left and right ITA</td>
<td>0/15</td>
<td>1/15</td>
<td>0/15</td>
</tr>
<tr>
<td>GA, h</td>
<td>4.6 (0.4)</td>
<td>4.7 (0.9)</td>
<td>4.6 (0.9)</td>
</tr>
<tr>
<td>CPBP, min</td>
<td>82.3 (19.7)</td>
<td>88.0 (21.1)</td>
<td>91.6 (20.3)</td>
</tr>
<tr>
<td>Cross clamp, min</td>
<td>39.3 (13.3)</td>
<td>41.5 (11.5)</td>
<td>42.1 (12.9)</td>
</tr>
</tbody>
</table>

*Values are mean (SD). CPBP=cardiopulmonary bypass pump; GA=general anesthetic.
†All patients had a leg incision for a saphenous vein graft.
that on day 2 or day 3 (p>0.05); however, PEFR on day 2 was significantly lower than that on day 3 (p<0.05).

**DISCUSSION**

During the first 72 h after CABG, TENS was no more effective than either placebo or control treatments in limiting pain at rest and with cough, intake of narcotic medication, or improving pulmonary functions (FVC, FEV\(_1\), and PEFR). The single instance of a significant treatment difference was for pain at rest, with less pain reported by the TENS than the control group—when scores were averaged over the 3 days (p<0.05; Fig 1). However, the TENS and placebo TENS treatments, and the placebo TENS and control treatments did not differ significantly (p>0.05). As a result, no unique effect due to TENS was observed in this study.

Although our finding that TENS was generally not advantageous following coronary artery surgery disagrees with previous research,\(^9\)\(^-\)\(^11\) methodologic differences among studies preclude a generalized statement as to the effectiveness of TENS. Klin et al\(^9\) studied only TENS groups and reported no statistical procedures. In the study of Navarathnam et al\(^10\), pain was assessed subjectively by the nursing staff, and \(t\) tests were used to compare TENS and placebo TENS groups on each of the 3 days, resulting in a tendency to inflate the overall alpha level. Even so, only 4 of the 12 \(t\) tests produced significant differences in favor of the TENS treatment—pain and FVC were significantly different on day 2, while PEFR was greater on days 1 and 2 (p<0.05). Bayindir et al\(^11\) used TENS for a period of 180 min, beginning about 4 h after surgery. In the present study, TENS, placebo TENS, and control treatments were commenced about 24 h after surgery, continued uninterrupted for 48 h, and were compared using ANOVA tests. Although six ANOVAs were conducted, only one instance of a treatment-related effect was observed.

In addition, the therapeutic role of TENS may have been viewed differently by previous investigators. Navarathnam et al\(^10\) and Bayindir et al\(^11\) used TENS as the first treatment for pain control, before morphine or other medications were given. As a result, there may have been an expectation among patients that TENS (or placebo TENS) would be effective. In the present study, TENS was used as an adjunct to analgesics, such that pain medications were provided based on the patient’s request and assessment by nursing/medical staff, regardless of the TENS treatment group. Furthermore, care was taken not to overemphasize the potential value of TENS. As a result, our patients may not have thought that TENS would be effective to the same extent as in other studies.\(^10\)\(^,\)\(^11\) The inclusion of a control group in the present study enabled us to address the question of expectation associated with having a TENS unit (whether functional or not), and we found no significant differences between TENS, placebo TENS, and control groups.

Whereas previous studies included male and female patients with a variety of cardiac surgeries,\(^9\)\(^-\)\(^11\) the present study was limited to male patients undergoing CABG using ITA. In comparison to CABG without ITA, the additional stretch of the chest wall required to dissect the ITA from inside the chest wall may cause more bleeding and pleural fluid drainage, with increased discomfort of the chest and/or shoulder on the side of the ITA graft.\(^3\)\(^,\)\(^6\)\(^,\)\(^24\) Previous investigators have reported that patients with ITA dissection for CABG required more narcotics than did patients who had only saphenous vein

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21703/ on 06/27/2017)
grants. As a result, CABG with ITA may be one of the most painful cardiac procedures, and may be too painful for TENS, as used in the present study, to have a significant effect on pain or pulmonary function during the initial postoperative period. This suggestion is in agreement with previous observations that when pain levels are severe during the short-term postoperative period, TENS may not be of major benefit to regular opiate analgesics.

The trend for pulmonary functions (FVC, FEV1, and PEFR) to decrease significantly after CABG surgery, and to remain depressed for at least 3 to 8 days has been reported previously. Ferdinanad et al. also reported that patients who had undergone CABG with ITA demonstrated poorer pulmonary function than did those with saphenous vein grafts alone, further suggesting the dissection of the ITA may accentuate pulmonary dysfunction in the early postoperative period.

Clinically, deep breathing and coughing are performed to clear airway secretions and prevent respiratory complications after major surgery. In the present study, the highest levels of pain were reported with coughing. Both pain at rest and pain with cough were highest on days 1 and 2, and decreased by day 3, although pain with cough did not decrease to the same extent as did pain at rest (Fig 1). Similar patterns have been reported for pain at rest following CABG, and for pain at rest and after coughing following cholecystectomy. These results suggest that forced expiratory maneuvers produce a dramatic increase in pain, which in our experience was not affected by medications or TENS.

Although pain with cough produced higher overall mean scores (6.3 ± 2.1) than did pain at rest (2.8 ± 2.6), pain at rest was more variable. As a result, given the overall (pooled) SDs observed and the assumption that a 2.5-point difference between treatment groups on the verbal numeric pain scale would be clinically meaningful, our final sample size of 15 was slightly less than the 17 which would have been calculated for pain at rest, and more than the 11 which would have been calculated for pain with cough. However, if smaller differences between groups on the pain scale are considered clinically meaningful, additional subjects would be required to achieve comparable statistical power.

The present study does not discount the efficacy of TENS during the short-term postsurgical period, but indicates that the specific protocol that was used was not advantageous. Perhaps the use of TENS over short time intervals, rather than continually, may be advantageous by minimizing accommodation or habituation to TENS. Lack of habituation to TENS sensation may help explain why significant effects of TENS after abdominal surgery, thoracotomy, and cardiac surgery have been demonstrated in studies in which conventional TENS was applied for short periods (from 10 to 180 min of treatment time). A second factor that may be modified is the intensity of TENS, which in our study was adjusted to provide a strong, but comfortable tingling sensation. Whether use of a stronger more powerful TENS intensity would be more advantageous is unclear. Nevertheless, both variations in the duration and the intensity of TENS treatments should be investigated in view of the conflicting results reported to date.

**Conclusion**

TENS was no more effective than placebo TENS or control treatments in decreasing pain at rest and with cough, limiting narcotic medications intake, or in preventing decreases in FVC, FEV1, and PEFR. As a result, high-frequency, continuous TENS, as used in the present study, does not appear advantageous as a means of controlling pain or improving pulmonary function during the 24- to 72-h period following CABG with ITA.

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