doi:10.1510/icvts.2007.168542

INTERACTIVE CARDIOVASCULAR AND THORACIC SURGERY

Interactive CardioVascular and Thoracic Surgery xxx (xxx) xxx–xxx

www.icvts.org

Work in progress report - Cardiac general

Short-term transcutaneous electrical nerve stimulation after cardiac surgery: effect on pain, pulmonary function and electrical muscle activity

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Received 19 September 2007; received in revised form 22 March 2008; accepted 25 March 2008

Abstract

This study aimed to evaluate the effectiveness of transcutaneous electrical nerve stimulation (TENS) for treatment of postoperative pain in patients who underwent cardiac surgery. In addition, we sought to determine whether TENS would be related to improved pulmonary function and muscle electrical activity in this patient population. Forty-five patients, 32 males and 13 females, aged 41–74 years were randomly allocated to receive TENS ($n=23$) or sham treatment ($n=22$) during 4 h on the third postoperative day. A 0–10 visual analogic scale was used to assess pain; lung function was evaluated by spirometry and surface electromyography ($n=10$ in each group) was used to quantify electrically-induced muscle activity (*trapezius* and *pectoralis major*). TENS was associated with significant reductions on spontaneous and cough-induced postoperative pain as compared to sham ($P<0.05$). There was also improvement in chest wall-pulmonary mechanics after TENS with proportional increases in tidal volume and vital capacity ($P<0.05$). In addition, electrical activity of both muscle groups was enhanced after TENS, but not post sham ($P<0.05$). TENS is a valuable strategy to alleviate postoperative pain following cardiac surgery with positive effects on pulmonary ventilatory function and electrical activity of thoracic and girdle muscles.

Keywords: Transcutaneous electrical nerve stimulation; Cardiac surgery; Pain; Pulmonary function; Electromyography

1. Introduction

Cardiac surgery is a life-saving procedure which is frequently related to significant postoperative pain [1]. A number of lung defense mechanisms may become impaired, or overtly ineffective, due to intense chest pain: deep breathing, body mobilization and, in particular, coughing [2]. Although narcotics and opiates may be effective for pain control, they are associated with side effects, including respiratory depression [3]. Therefore, there is a long-standing interest in the development of non-chemical strategies for effective pain control.

Transcutaneous electrical nerve stimulation (TENS) has been used since the early 1970s as an adjunctive therapy for chronic and acute pain control in several medical and surgical conditions [4]. TENS has also been shown to be effective in the postoperative period of cardiac and non-cardiac thoracic surgery [5–9]. However, the positive effects of TENS have not been uniformly reported: some researchers found that TENS was not effective in all patients, especially in those with more intense pain [7, 8]. In addition, decline on pulmonary-ventilatory function was not always lessened after TENS [7]. Therefore, the actual role of TENS in controlling post-CABG pain and its undesirable consequences is still controversial.

The present study was undertaken to evaluate if short-term TENS (4 h) would present with positive effects on postoperative pain, pulmonary function and local muscle electrical activity after cardiac surgery as compared to placebo TENS.

2. Material and methods

Forty-five patients (aged 41–77 years, 32 males and 13 females) from the teaching hospital of the Federal University of São Paulo comprised the study group. All patients underwent cardiac surgery through median sternotomy by the same surgical team and intra-operative anesthesic protocol. The surgeries included coronary artery bypass graft (CABG) ($n=34$), valve replacement ($n=5$), aortic surgery ($n=5$) and Mixom ($n=1$). From 34 patients who were submitted to CABG, saphenous vein ($n=33$) and internal thoracic arteries ($n=30$) were used for grafting. They had no other abnormalities or conditions that required another surgery at the time of the cardiac surgery. Informed consent (as approved by the Institutional Medical Ethics

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Committee) was obtained from all patients before the surgical procedure.

2.1. Design and procedures

This was a prospective and randomized study. The patients were randomly allocated to the treatment arm only after surgery as peri-incisional pain was an inclusion criterion. Out of 49 patients, four did not report significant pain. The other 45 subjects were then submitted to TENS ($n=23$, 16 males, aged 44–77 years, body mass index$=26.3\pm3.5$ kg/m^2) or sham TENS ($n=22$, 16 males, aged 41–75 years, body mass index$=26.5\pm3.3$ kg/m^2). In the first preoperative day, the patients were submitted to spirometry; in addition, electrical activity of selected girdle and upper thoracic muscle (*trapezius* and *pectoralis major*, respectively) was recorded. Patients were then familiarized with the TENS equipment and an analogue-visual scale. After returning on the third postoperative day, the above-mentioned outcomes were obtained before and after TENS or sham TENS. The treatment was applied after the patients had remained at least 8 h without pharmacological analgesia.

2.2. Transcutaneous electrical stimulation

TENS and sham stimulation were delivered by a portable stimulator (TENS Device™, KLD, Amparo, SP, Brazil). The electrical current was delivered by two self-adhesive surface electrodes (10×3.5 cm), which were placed at the subclavicular region on either side of the incision, approximately 2–3 cm from the suture line. During the 4-h treatment period, pulse duration was kept constant (150 μs) at a wave frequency of 80 Hz and a duty cycle (on:off time) of 330/33 ms [10, 11]. The sham stimulation equipment had the internal programming modified in order to reduce the rest time between the pulses from 350 ms to 330 s, without significant changes in sensations produced by the stimulator. Therefore, after 4 h TENS group received almost 240 min of active treatment current while the sham group received only 2.37 min of active current.

Treatment duration was selected considering the local characteristics of the postoperative unit: we reasoned that longer stimulation period would significantly affect the routine of patient's care. Patients adjusted the stimulation intensity to the point that they felt a strong, but comfortable tingling sensation: they were specifically instructed as reduce the stimulation intensity in case of pain. The same equipment and treatment duration were used to deliver sham TENS: the patients received identical instructions as those in the active treatment group, even if they were not sure if they were feeling any electrical current. They were instructed that after some time with the equipment, it could produce a continuous or intermittent current, being both aimed to produce analgesia.

2.3. Measurements

2.3.1. Spirometry

Spirometric tests were performed by using the Spirobank G™ (Medical International Research, Rome, Italy) with airflow being measured by a calibrated turbine. The subjects completed at least three acceptable maximal slow expiratory maneuvers: vital capacity (VC, l) was recorded. Tidal volume (V_T, ml) and respiratory rate (RR, bpm) were also obtained.

2.3.2. Electrical muscle activity by biofeedback (surface electromyography)

Muscle electrical activity of the *trapezius* and the *pectoralis major* was obtained by using the Myomed 932™ System (Enraf Noniuns, Rotterdam, The Netherlands): positioning of a reference and two exploratory electrodes were standardized as described elsewhere [12]. In the present study, the patients were asked to perform a maximum voluntary contraction against a fixed resistance during 4–5 s at standardized positions [12]. The maneuvers were performed in triplicate: the highest and the average value of electrical potential (mA) were recorded.

2.3.3. Pain

The participants were asked to quantify their incision pain using a numbered 10-cm analogue-visual scale ranging from 0 ('no pain at all') to 10 ('the worst imaginable pain') [13]. The scale was applied at rest and after the patients had coughed.

2.4. Statistical analysis

Mean and standard deviations (S.D.) were obtained for spirometric and electromyographic data in subjects of both groups. Pain scores are reported as median and interquartile range. Repeated measures analysis of variance was used to assess the effects of TENS and sham stimulation. The probability of a Type I error was established at 0.05 ($P<0.05$).

3. Results

3.1. Effects of TENS on pain

As expected, cardiac surgery was associated with significant pain, either spontaneously or after cough (Table 1). Electrical stimulation was well-tolerated by all patients and no relevant side effect was observed. There was a systematic decrease in pain after TENS treatment, especially cough-related pain: as shown in Fig. 1, all patients had lower pain scores (at least 1 U less) after active stimulation. Accordingly, TENS, but not sham, was related to significant decrease in median pain scores (Table 1). Improvement in pain was negatively associated with baseline pain: from nine patients with 'severe' pain (>7 U), seven of them decreased at least 3 U after TENS (Fig. 2).

3.2. Effects of TENS on pulmonary function

There were significant differences between pre- and postoperative values of all lung function variables: cardiac surgery was associated with lower tidal volume (V_T) which reduction was less than that found for vital capacity (VC), i.e. V_T/VC increased after surgery in both groups. As overall pulmonary-ventilation did not change, the patients adopted

Table 1
Effects of transcutaneous electrical nerve stimulation (TENS) and sham TENS on pain (visual analogue scale, VAS), pulmonary mechanics and electrically-induced muscle activity in patients who underwent cardiac surgery

	TENS (n=23)			Sham stimulation (n=22)		
	Preoperative	Postoperative		Preoperative	Postoperative	
		Pretreatment	Posttreatment		Pretreatment	Posttreatment
Pain score (VAS)						
Spontaneous	–	3 (2)	2 (1)	–	3 (1,5)	3 (2,25)
Cough-induced	–	7 (2)	4 (2)	–	6 (1,5)	5 (2)
Lung function						
V_E (l/min)	8.2±1.9	7.8±2.0	8.5±2.0	8.1±1.9	8.6±2.0	8.1±1.9
V_T (l)	0.47±0.08	0.38±0.07*	0.46±0.08**	0.51±1.02	0.45±0.07*	0.43±0.06
RR (bpm)	17±3	20±4*	18±3**	15±2	18±3*	18±3
VC (l)	2.32±0.65	1.52±0.44*	1.83±0.41**	2.84±0.69	1.81±0.57*	1.88±0.58
V_T/VC	0.21±0.05	0.27±0.05*	0.26±0.06	0.19±0.05	0.27±0.09*	0.25±0.09
RR/V_T	36.4±8.2	54.0±10.7*	40.9±10.0**	31.7±7.9	42.3±9.5*	43.7±9.4
Electromyography†						
Trapezius						
Mean potential, mA	637±53	447±39*	525±44**	623±71	452±71*	433±130
Peak potential, mA	796±83	551±67*	651±80**	808±61	578±68*	593±63
Pectoralis Major						
Mean potential, mA	171±28	105±10*	147±20**	171±25	105±9*	111±11
Peak potential, mA	200±28	114±10*	175±19**	205±32	120±13*	127±12

V_E, minute ventilation; V_T, tidal volume; RR, respiratory rate; VC, vital capacity. Data are reported as mean±S.D., with exception of pain scores (median and interquartile range).
$P<0.05$: *Preoperative vs. pretreatment postoperative; **post- vs. pretreatment in the postoperative period. †n=10 in each group.

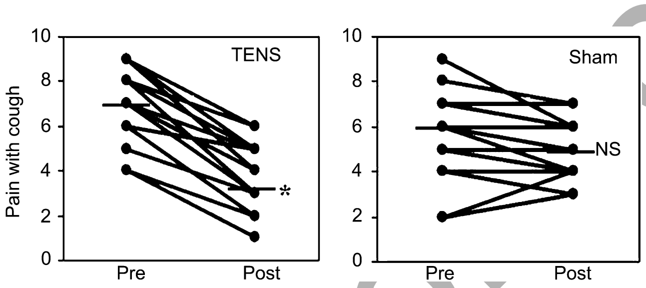

Fig. 1. Individual and mean effects of TENS (n=23) and sham (n=22) stimulation in cough-induced incisional pain after cardiac surgery (data are overlayed). *$P<0.05$.

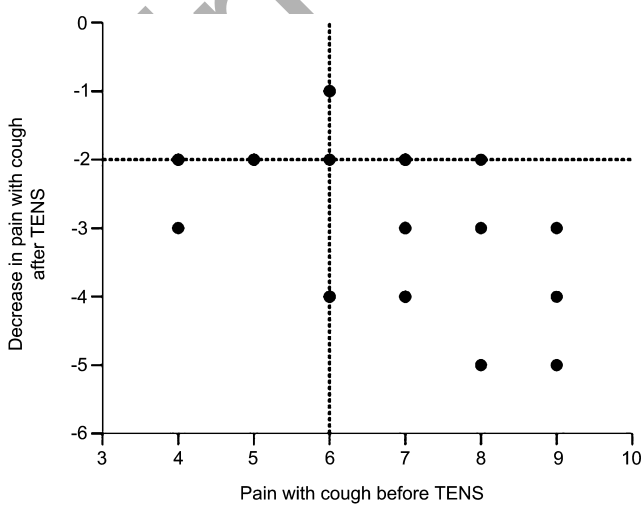

Fig. 2. Association between pre- and post-TENS pain with cough: note that substantial reductions in pain with TENS (<2 U) were more frequent in patients with higher pre-TENS scores (above 6).

a more tachypneic breathing pattern to attain the ventilatory demands (Table 1). After TENS treatment, there were significant and proportional increases in both V_T and VC at similar ventilatory levels (Fig. 3). In addition, respiratory rate (RR) and the RR/V_T ratio decreased only in the active treatment group ($P<0.05$).

3.3. Surface electromyography

In similarity with the above-mentioned data, mean and peak electrical potentials recorded in the *trapezius* and *pectoralis major* were found to be reduced in either group after surgery (n=10 in each group). After TENS, but not

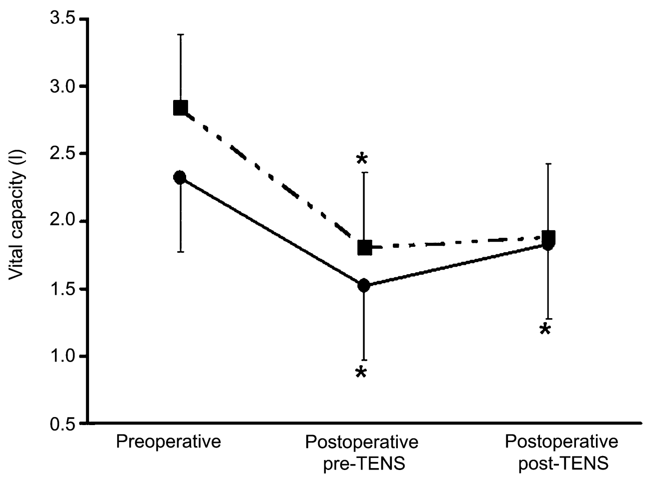

Fig. 3. TENS stimulation (solid lines), but not sham (dotted lines), was associated with a significant increase in vital capacity in the postoperative period. *$P<0.05$ (within-treatment effect).

sham treatment, there were significant improvements in the electromyographic variables recorded at both muscle groups (Table 1).

4. Discussion

This prospective and randomized investigation evaluated the effects of transcutaneous electrical nerve stimulation (TENS) in the postoperative management of pain in patients who were submitted to different cardiac surgeries. We found that TENS presented with beneficial effects not only in postoperative pain, but also in selected pulmonary-mechanical properties and electrical activity of thoracic and girdle muscles. These data point out for a relevant role of TENS in the postoperative care of cardiac surgery patients.

A number of strategies have been used to control pain and its deleterious consequences after cardiac surgery, including TENS [5–9]. Although the precise mechanism(s) for TENS-related hypoalgesia is currently unknown, they could include peripheral blocking of nociceptive input, activation of descending inhibitory feedback circuits, 'gating' of noxious stimuli at spinal segmental level, and/or activation of either opioid and non-opioid systems at a cortical level [14]. In the present study, we were able to confirm previous reports that TENS is effective and well-tolerated for the control of mild to moderate post-thoracotomy pain (Fig. 1) [5, 6, 9]. However, even in patients with more severe pain TENS showed to be useful (Fig. 2): these data suggest that, at least when applied for a short period of time (4 h), TENS may also be effective in these patients.

Although median sternotomy is known to be associated with less respiratory morbidity than postero-lateral incisions, the former also is related to pulmonary-mechanical abnormalities (Table 1) and more frequently performed than the later. Postoperative reduction in VC (i.e. the difference between total lung capacity and residual volume) after cardiac surgery is a consequence of pain and decrease in rib cage compliance [15]. However, the closing volume of the dependent, small airways may also contribute to increased residual volume, and shallow breathing due to pain is known to increase these volumes [15]. We found that TENS significantly lessened the postoperative decrease in VC and V_T with no change in V_T/VC ratio. i.e. a higher VC after TENS is prone to be positively associated with a deeper breathing pattern (Fig. 3).

Another interesting finding of the present study was the significant improvement in electrical activity of girdle and thoracic muscles after TENS (Table 1). Surface electromyography with biofeedback presents with high external validity, since the potential is evoked by active movement and it is likely to be relevant for patients' functioning [12]. Our results seem to indicate that pain relief after stimulation improves motor activity of the muscles which are centrally-related to chest displacement – with potential beneficial effects in coughing, sighing and effective clearance of secretions [2].

This study presents a number of important limitations. Initially, we evaluated a relatively small number of patients on the third postoperative day: we therefore could not assess the effects of TENS on a more heterogeneous sample presenting with more severe pain. For instance, Erdogan et al. have recently found that TENS was highly effective in lessening pulmonary gas exchange after posterolateral thoracotomy [9]. Another important caveat was the lack of standardization of the use of analgesics during the intervention and control periods: previous studies have found that TENS may be useful in reducing the need of opiates for pain control [5, 6, 9]. However, most of our patients were not using opiates at the time of the study and due to the short-term nature of the intervention it was not possible to assess any change on daily need of analgesics. In fact, we were unable to evaluate whether longer periods of TENS would be also beneficial for cardiac surgery patients – although this was the case in those studies in which TENS was continuously applied for up to five days [5, 6, 9]. Another potential limitation was related to the fact that patients underwent a number of different cardiac surgery procedures. However, the same surgical access (median sternotomy) was used in all patients and the patients were free from additional cause of chest pain, such as chest tubes or mediastinitis. Finally, electrical muscle activity evaluation could be performed in only 20 participants due to financial constraints, nevertheless, the sample size was large enough to unravel a positive effect of TENS.

In conclusion, this prospective and randomized study demonstrated that TENS is a valuable strategy to alleviate postoperative incisional pain following cardiac surgery with positive effects on pulmonary ventilatory function and local muscle electrical activity.

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