J Anesth (2017) 31:58–65
DOI 10.1007/s00540-015-2057-1

ORIGINAL ARTICLE

Effects of transcutaneous electrical acupoint stimulation at different frequencies on perioperative anesthetic dosage, recovery, complications, and prognosis in video-assisted thoracic surgical lobectomy: a randomized, double-blinded, placebo-controlled trial

Shun Huang[1,2] · WenPing Peng[2] · Xue Tian[1] · Hansheng Liang[1] · Zhe Jia[3] · Theresa Lo[4] · Miao He[1] · Yi Feng[1]

Received: 18 April 2015 / Accepted: 19 July 2015 / Published online: 8 September 2015
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Abstract
Background Transcutaneous electrical acupoint stimulation (TEAS), a non-invasive and non-pharmacological adjunctive intervention for perioperative analgesia, may also reduce the incidence of postoperative pulmonary complications. The effect of TEAS on video-assisted thoracic surgical (VATS) patients is still unknown, however. The purpose of this study was to investigate the effects of TEAS of different frequency on perioperative anesthetic dosage, recovery, complications, and prognosis for patients undergoing VATS lobectomy.
Methods Eighty VATS lobectomy patients with no previous experience of TEAS or acupuncture were randomly assigned to four groups: control (con), 2/100, 2, and 100 Hz. The last three experimental groups received TEAS at the indicated frequencies for 30 min before induction, during the operation, and for another 30 min 24 and 48 h after surgery. 2/100 Hz is a type of alternating frequency which goes between 2 and 100 Hz every 3 s. TEAS was administered over acupoints Neiguan, Hegu, Lieque, and Quchi on the sick lateral. Electrodes were applied to the patients in the control group, but no TEAS was used. Anesthetic dosage, blood gas analysis results, lung function indexes FEV_1 and FVC, post-anesthesia care unit (PACU) status, postoperative complications, and quality of life scores were recorded and analyzed statistically.
Results Intraoperative opioid consumption was lowest in the 2/100 Hz group, with statistical significance (con, $P \leq 0.001$; 2 Hz, $P \leq 0.001$; 100 Hz, $P = 0.026$). Compared with preoperative FEV_1 and FVC, postoperative FEV_1 and FVC were significantly lower in all groups; during one-lung ventilation, arterial oxygen partial pressure (PaO_2) decreased more slowly in the 2/100 Hz group than in the con group ($P = 0.042$). Moreover, in the 2/100 Hz group extubation time was shorter ($P = 0.038$), visual analgesia scale score lower ($P = 0.047$), and duration of PACU stay shorter ($P = 0.043$) than in the con group. In the 100 Hz group incidence of postoperative nausea and vomiting (PONV) was lower than the con group ($P = 0.044$). In all groups mean postoperative physical component scores were significantly lower than mean preoperative scores.
Conclusions TEAS is a safe noninvasive adjunctive intervention for anesthesia management among patients undergoing VATS lobectomy. TEAS at 2/100 Hz can reduce intraoperative opioid dosage and slow the decrease of PaO_2 during one-lung ventilation. It can also effectively reduce pain score, extubation time, and PACU stay immediately after surgery. Further, 100 Hz TEAS can reduce PONV morbidity.

Keywords Transcutaneous electrical acupoint stimulation · Opioid · Lung function · Video-assisted thoracic surgery · Lobectomy

Clinical trial registration: The trial was registered at www.chictr.org (ChiCTR-TRC-14004207).

S. Huang and H. Liang have contributed equally to this work and share the first authorship.

✉ Yi Feng
yifeng65@sina.com

Shun Huang
huangshunsleet@126.com

1 Department of Anesthesiology, Peking University People's Hospital, Beijing 100044, China

2 Department of Anesthesiology, Ministry of Health Beijing Hospital, Beijing 100730, China

3 Department of Surgery, Beijing Oasis International Hospital, Beijing 100015, China

4 Department of Anesthesiology, Ronald Reagan UCLA Medical Center, Los Angeles, CA 90095-7403, USA

Introduction

Video-assisted thoracic surgical (VATS) lobectomy is a newly developed surgical procedure comparable in efficacy with traditional thoracotomy but less likely to cause further trauma, pain, and perioperative morbidity [1]. Although postoperative pulmonary complications after VATS are associated with high morbidity and mortality, they can be prevented by appropriate application of anesthesia, postoperative analgesia, and physical therapy [2].

Clinical studies in the early 1980s showed that acupuncture is an effective and safe alternative method of anesthesia in lung resection [3], and a recent meta-analysis provided clear evidence that acupuncture is of benefit for chronic pain management [4]. Acupuncture has even been reported as a safe and effective intervention for breathlessness caused by respiratory diseases [5, 6], and several studies have reported that combined application of acupuncture and general anesthesia is beneficial in pneumonectomy [7, 8].

Transcutaneous electrical acupoint stimulation (TEAS), a noninvasive adjunctive intervention based on acupuncture, may reduce pulmonary inflammatory responses induced by one-lung ventilation, and therefore reduce the incidence of postoperative pulmonary complications [9]. Different frequencies of TEAS are known to have different effects on immune function, stress reaction, and even on levels of serum components among patients undergoing pneumonectomy [10–12].

As far as we are aware, the effects of different frequencies of TEAS on perioperative anesthetic dosage, recovery, complications, and prognosis among patients undergoing VATS lobectomy have not been investigated. Therefore, in this study, we combined TEAS and general anesthesia for VATS lobectomy patients and observed the effects of different frequencies of TEAS on perioperative anesthetic dosage, recovery, complications, and prognosis for this cohort.

Materials and methods

Participants

This study was approved by the Institutional Review Board of Peking University People's Hospital and performed in accordance with the Declaration of Helsinki. The trial is registered at www.chictr.org (ChiCTR-TRC-1400420). Written informed consent was obtained from all participants. Patients undergoing selective VATS lobectomy between January 2014 and April 2014 were recruited. Exclusion criteria were: severe co-existing disease with American Society of Anesthesiologists status IV, recent use of TEAS or acupuncture, and neural damage or infection along the meridian on which the acupoints lay. Demographic data age, gender, weight, height, body mass index, smoking history, and medication were recorded for all patients.

Design

A randomized, placebo-controlled, double-blinded study with a pre and post-test design was conducted in accordance with the STRICTA recommendations [13]. Patients were screened by the investigators the day before they underwent VATS lobectomy. Eligible participants were randomly assigned to the 2/100, 2, or 100 Hz experimental (TEAS) group or the control (placebo-TEAS) group depending on enrollment sequence according to a series of random numbers generated by Excel. We chose these frequencies because they are representative and in common use, one is low frequency, one is high frequency, and one is an alternating frequency.

All participants were unaware of group allocation. A single investigator was responsible for application of both types of intervention. The data were collected by another investigator unaware of the group allocation.

Intervention

The acupoints Neiguan (PC6), Hegu (LI4), Lieque (LU7), and Quchi (LI11) on the surgery-lateral were identified in accordance with traditional anatomic location, marked, and cleaned with an alcohol swab to reduce resistance. Electrodes (50×50 mm^2) were then placed over each acupoint, with the pore directly over the marked acupoint. Tegaderms were placed over the electrodes and the participant's skin to fix the electrodes during intervention.

We used HANS-200A Acupoint Stimulator for TEAS. The intensity was set at the highest tolerable level that caused no discomfort to the participant. The frequency was set as 2/100, 2, or 100 Hz for the experimental groups. 2/100 Hz stimuli were in the dense-and-disperse mode, in which 2 and 100 Hz are alternated every 3 s. Before data collection, the voltage output of the machine was confirmed to be reliable by use of a laboratory oscilloscope. In the control group (con), electrodes with no central pore were placed on the skin over the marked acupoints. The participants could see the output light flashing but no current was transmitted to the acupoints. We also told patients in control group that this was a type of stimulus without perception.

All participants received 30 min of TEAS or placebo-TEAS before induction, during the entire intraoperative period, and 30 min of TEAS or placebo-TEAS 24 and 48 h after surgery.

Anesthesia procedures

First, a 16-G intravenous catheter and 20-G intra-arterial catheter were placed in the non-surgery-lateral forearm, lactated Ringer's solution or colloid was administered, and devices to monitor echocardiograms, peripheral capillary oxygen saturation (SpO_2), arterial blood pressure, bi-spectrum index (Philips IntelliVue MP70, Royal Dutch Philips Electronics), and anesthesia nociception index (ANI; Metrodoloris, Lille, France) were placed. ANI is an indicator for monitoring nociception during general anesthesia, which is calculated on the basis of heart rate variability. ANI provides an even faster response than fluctuation of the cardiovascular system [14, 15]. As far as we are aware, no study has shown that TEAS itself affects heart rate variability and ANI, so we used ANI to determine the dosage of the intraoperative opioid. After 30 min of TEAS or placebo-TEAS, intravenous induction was started with 1.5–2 mg/kg propofol, 0.2–0.4 µg/kg sufentanil, and 0.2 mg/kg cisatracurium. The patient was intubated with a double-lumen tube at the appropriate depth. Mechanical ventilation was started after the tube position was confirmed by auscultation, and fiber optic bronchoscopy was performed to reconfirm the tube position. During the operation, peak airway pressure, end tidal CO_2, and SpO_2 were maintained at 15–30, 30–35 mmHg, and >93 %, respectively.

Anesthesia was maintained by continuous infusion of cisatracurium (0.06 mg kg^{-1} h^{-1}) and target controlled infusion (TCI) of propofol and remifentanil. The bi-spectrum index was maintained within the range 40–60 by adjusting the propofol concentration, and ANI was maintained within the range 50–70 [14, 15] by adjusting the remifentanil concentration, according to the Marsh and Minto models, respectively. If the remifentanil target controlled infusion concentration reached 6 ng/mL but the ANI was still below 50, sufentanil (0.1 µg/kg) was administered. Body temperature (nasopharyngeal) was maintained at over 36 °C by use of a warm blanket. Heart rate and blood pressure were maintained with acceptable ranges, and vasoactive drugs were administered when needed.

Sufentanil (0.1 µg/kg), flurbiprofen (100 mg), and tropisetron (5 mg) were administered 30 min before the end of surgery for analgesia transition and prevention of postoperative nausea and vomiting (PONV). A patient-controlled intravenous analgesia pump was connected (1 µg/mL sufentanil and 1.2 mg/mL flurbiprofen; flow rate, 2 mL/h; bolus, 3 mL; lockout time, 15 min). On skin closure, administration of all anesthetics was stopped, and the surgeon administered intercostal nerve block with 0.5 % ropivacaine, 10 ml, after which the patient was transferred to the post-anesthesia care unit (PACU). After spontaneous breath recovery, the patient was given muscle relaxant reversal, neostigmine 2 mg, and atropine 1 mg, extubated when the required criteria were achieved [16], and discharged from the PACU after the modified Aldrete discharge criteria were achieved [17].

Outcome measurements

Surgery time and intraoperative dosages of sufentanil, remifentanil, propofol, and cisatracurium were recorded. Intraoperative sufentanil dosage was converted into remifentanil dosage on the basis of their relative potencies (ratio 1:10), [18] and total opioid dosage (remifentanil dosage) was calculated for comparison among groups. Blood gas analysis was conducted immediately after intubation and before the end of one-lung ventilation. FiO_2 was set as 50 % during ventilation. The PaO_2 change rate was calculated by use of the formula [(PaO_2 immediately after intubation − PaO_2 before the end of one-lung ventilation)/surgery time]. In the PACU, the extubation time (from cessation of anesthetic use to achievement of extubation criteria), numerical rating scale (NRS; 0 = "no pain at all"; 10 = "the worst pain ever experienced") immediately after extubation, and duration of PACU stay (from admission into the PACU to achievement of discharge criteria) were recorded.

The forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) were measured by use of a portable spirometer (Micro Lab, UK) on the day before surgery and the day after the drainage tube was removed, in accordance with American Thoracic Society recommendations [19]. All measurements were performed with the patient in the seated position, and the best value from 3 trials was recorded. The rates of change of these variables [(preoperative volume − postoperative volume)/preoperative volume] were calculated for comparison among groups.

After surgery, the dosages of sufentanil and flurbiprofen required after 6, 12, 24, and 48 h to maintain the NRS score at <4 were recorded. Complications including intraoperative awareness, PONV, dizziness, pruritus, and respiratory depression were recorded. Nausea and vomiting were evaluated 6, 12, 24, and 48 h after surgery, where 0 indicated "no nausea at all" and 10 indicated "the worst nausea ever experienced". The quality of life score was evaluated by use of the Medical Outcomes Study 12-item Short-Form Health Survey (SF-12) before surgery and 1 month after surgery, and the score was divided into the physical component score and mental component score.

Sample size

In the pre-study, the intraoperative opioid dosage in the control group was 0.1620 (0.035) µg kg^{-1} min^{-1}. On the basis of this value and assuming a two-tailed α of 0.05 and a power of 0.8, 11 patients were required in each group for a 30 % between-group difference to be detected. Considering potential loss of records and loss to follow-up, the sample size was increased to 20 cases per group.

Data analysis

Data are presented as means and standard deviations for continuous variables and as proportions for categorical variables. One-way ANOVA and the S–N–K post-hoc test were used for multiple comparisons of continuous variables, and the least-significant-difference test was used for paired comparisons of means between groups. The Pearson chi-squared test was used for categorical variables. A two-tailed P value of <0.05 was regarded as statistically significant. All analysis was performed with Statistical Package for IBM SPSS 22.0 (SPSS, Chicago, IL, USA).

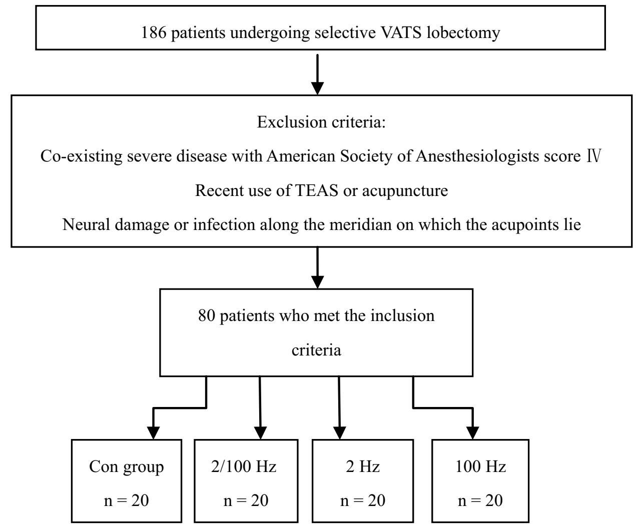

Fig. 1 Flow chart of trial distribution

Results

Of 186 screened patients, 80 patients met the inclusion criteria and were randomized to the 4 study groups (Fig. 1). All 80 patients completed the trial and reported no adverse effects such as intraoperative awareness or dizziness. No differences in anesthesia duration, operation duration, and one-lung ventilation duration were observed among the groups. Randomization resulted in equal distribution of socio-demographic and clinical characteristics, and surgery time was not statistically difference among groups (Table 1).

Intraoperative propofol and cisatracurium dosages did not differ significantly among groups. Intraoperative total opioid dosage (sum of remifentanil and sufentanil dosages) was significantly lower in the 2/100 Hz group than in the other groups ($P = 0.001$ compared with the control group and 2 Hz group; $P = 0.026$ compared with the 100 Hz group) (Table 2).

Most of the drain tubes of our patients were removed within 3 days of surgery; the mean time was no different among groups. Compared with the preoperative FEV_1 and FVC, the postoperative FEV_1 and FVC were significantly lower in all groups, but the rate of change in these variables was not significantly different among the groups. Blood gas analysis indexes pH, HCO_3^{-1}, and SaO_2 were not significantly different among the groups. In all groups, PaO_2 was significantly lower after longer one-lung ventilation than before; the rate of change of PaO_2 in the 2/100 Hz group decreased more slowly than in the control group ($P = 0.042$; Table 3).

With regard to the patients' status in the PACU, extubation time was shorter ($P = 0.028$), VAS score lower ($P = 0.047$), and duration of PACU stay shorter ($P = 0.043$) for the 2/100 Hz group than for the control group. No patient experienced PONV in the PACU (Table 4).

Neither the required dosages of sufentanil and flurbiprofen nor the scores for nausea and vomiting 6, 12, 24, and 48 h after surgery differed significantly among groups. However, PONV morbidity was lower for the 100 Hz group than for the control group ($P = 0.044$) (Table 5).

Six patients (3 who received interventions and 3 controls) had no SF-12 score because they were lost to follow-up. Analysis of SF-12 data from 74 patients 1 month after surgery showed that the mean postoperative physical component scores were significantly lower than the mean preoperative scores in all groups (control group, $P = 0.046$; 2/100 Hz group, $P = 0.038$; 2 Hz group, $P = 0.029$; 100 Hz group, $P = 0.041$). In contrast, the mean postoperative mental component scores were similar to the mean preoperative scores in all groups (Table 6). These values were not significantly different among the groups.

Discussion

In this study, we found that 2/100 Hz TEAS reduced intraoperative opioid consumption and anesthetic recovery time, and slowed the rate of change of PaO_2 during one-lung ventilation; 100 Hz TEAS reduced PONV morbidity.

Minimally invasive surgery and non-invasive adjunctive anesthetic methods have become increasingly popular. In this study, we examined the effects of TEAS at different frequencies with general anesthesia for VATS lobectomy patients to identify the overall effects of TEAS on

Table 1 Patient characteristics

Characteristic	Con	2/100 Hz	2 Hz	100 Hz
Age (year), mean (SD)	57.2 (15.7)	57.3 (11.6)	58.2 (10.6)	56.5 (11.2)
Gender (*n*), male/female	9/11	10/10	9/11	9/11
Body mass index (kg/m^2), mean (SD)	22.8 (2.6)	24.7 (2.2)	25.0 (3.5)	23.6 (2.2)
Smoking status (*n*), smoker/nonsmoker	3/17	8/12	6/14	7/13
American Society of Anesthesiologists status (*n*), I/II/III	7/12/1	6/14/0	8/12/0	10/7/3
Lobectomy (*n*), single/two lobes	19/1	19/1	20/0	19/1
Surgery time (min), mean (SD)	144 (23.1)	142 (22.7)	138 (19.3)	140 (20.2)

Con control

Table 2 Intraoperative anesthetic dosage

Anesthetic	Con	2/100 Hz	2 Hz	100 Hz
Propofol ($mg\ kg^{-1}\ min^{-1}$) mean (SD)	0.1355 (0.028)	0.1365 (0.025)	0.1242 (0.032)	0.1308 (0.028)
Cisatracurium ($\mu g\ kg^{-1}\ min^{-1}$) mean (SD)	2.89 (0.37)	2.95 (0.65)	2.70 (0.76)	2.76 (0.40)
Total opioid dose (remifentanil) ($\mu g\ kg^{-1}\ min^{-1}$) mean (SD)	0.1617 (0.037)	0.1128 (0.034)$^{*\#\Delta}$	0.1718 (0.066)	0.1451 (0.036)

Con control

* 2/100 Hz vs. con, $P \leq 0.001$; $^{\#}$ 2/100 Hz vs. 2 Hz, $P \leq 0.001$; $^{\Delta}$ 2/100 Hz vs. 100 Hz, $P = 0.026$

Table 3 Pulmonary functions and arterial oxygen partial pressure changes

Indicator	Con	2/100 Hz	2 Hz	100 Hz
PaO_2 change rate (mmHg/min), mean (SD)	1.28 (0.78)	0.76 (0.95)*	0.88 (0.84)	1.25 (0.52)
FEV_1 change (%), mean (SD)	36 (10)	38 (9)	39 (10)	37 (9)
FVC change (%), mean (SD)	41 (9)	39 (10)	42 (11)	44 (13)

Con control, PaO_2 arterial oxygen partial pressure, FEV_1 forced expiratory volume in 1 s, *FVC* forced vital capacity

* 2/100 Hz vs con, $P = 0.042$

Table 4 PACU status

Indicator	Con	2/100 Hz	2 Hz	100 Hz
Extubation time (min), mean (SD)	14.7 (4.0)	9.9 (3.5)*	12.4 (4.6)	12.8 (6.2)
NRS score right after extubation, mean (SD)	2.4 (0.5)	1.3 (0.7)$^{\#}$	2.2 (1.9)	2.4 (1.3)
Duration of PACU stay (min), mean (SD)	29.3 (8.0)	19.8 (7.0)$^{\Delta}$	24.9 (9.2)	25.6 (12.4)
PONV in PACU (%)	0	0	0	0

NRS numerical rating scale, *PACU* post-anesthesia care unit, *PONV* postoperative nausea and vomiting

* 2/100 Hz vs. con, $P = 0.028$; $^{\#}$ 2/100 Hz vs. con, $P = 0.047$; $^{\Delta}$ 2/100 Hz vs. con, $P = 0.043$

perioperative anesthetic dosage, lung function, recovery, complications, and prognosis. We chose the four forearm acupoints most widely accepted and commonly reported in the Chinese literature for management of pain, dyspnea, and nausea and vomiting; two of these are located on the lung meridian. We also used ANI as an indicator for monitoring nociception during general anesthesia, because it responds even faster than fluctuation of cardiovascular system [14, 15], making opioid administration more objective and accurate.

We demonstrated that 2/100 Hz TEAS reduced intraoperative opioid consumption by 33.5 %. This value however, cannot be compared with those observed in other similar studies on opioids because these studies used different procedures [7, 20–22]. This study had a strict double-blinded design, with ANI as a unique criterion for adjustment of opioid dosage.

Table 5 Postoperative medication and PONV

Indicator	Con	2/100 Hz	2 Hz	100 Hz
Sufentanil (μg/kg), mean (SD)	1.32 (0.48)	1.67 (0.59)	1.41 (0.52)	1.69 (0.50)
Flurbiprofen (mg/kg), mean (SD)	3.05 (2.23)	3.45 (2.12)	3.24 (1.98)	3.46 (1.79)
PONV 6 h score, mean (SD)	3.2 (0.7)	3.0 (0.8)	2.9 (0.4)	2.5 (0.4)
PONV 12 h score, mean (SD)	3.5 (0.5)	3.1 (0.7)	3.0 (0.6)	2.2 (0.5)
PONV 24 h score, mean (SD)	2.8 (0.6)	3.3 (0.8)	3.3 (0.7)	2.3 (0.4)
PONV 48 h score, mean (SD)	2.9 (0.7)	3.5 (0.6)	3.1 (0.5)	2.8 (0.7)
PONV morbidity (%)	35	25	26	5*

PONV postoperative nausea and vomiting

* 100 Hz vs. con, $P = 0.044$

Table 6 SF-12 quality of life scores

Indicator	Con	2/100 Hz	2 Hz	100 Hz
Preoperative PCS, mean (SD)	48 (7)	47 (9)	47 (11)	45 (8)
Postoperative PCS, mean (SD)	37 (8)*	35 (9)*	36 (8)*	36 (10)*
Preoperative MCS, mean (SD)	55 (7)	52 (8)	49 (9)	53 (6)
Postoperative MCS, mean (SD)	53 (9)	54 (9)	50 (8)	51 (7)

PCS physical component score, *MCS* mental component score

* Post vs. pre: con, $P = 0.046$; 2/100 Hz, $P = 0.038$; 2 Hz, $P = 0.029$; 100 Hz, $P = 0.041$

The mechanism of acupuncture analgesia is not well understood, and most basic research has focused on the production of endogenous opioid peptides and stimulation of endogenous descending inhibitory pathways. Analysis of cerebrospinal fluid of patients receiving acupuncture treatment has revealed elevated levels of serotonin, endorphins, and enkephalins [23]. Previous animal and human studies have found that low-frequency (2 Hz) and high-frequency (100 Hz) electrical acupuncture induced different release of a variety of opioid peptides. Studies have found that TEAS at 2 Hz induced release of enkephalins and endorphins, TEAS at 100 Hz induced release of dynorphins [24–26], and only TEAS at 2/100 Hz induced release of all opioid peptides, resulting in their synergistic interaction [27].This may explain our observation of different analgesia effects induced by different frequencies of TEAS.

There is a dose–response relationship between opioid dosage and associated side effects [28]. Hence, any non-pharmacological method that reduces use of opioid medication is likely to be beneficial. Similar to previous studies, we found that 2/100 Hz TEAS treatment significantly reduced the time to extubation, time to achieving discharge criteria, and the NRS score immediately after extubation [22, 29].Moreover, no patient reported PONV in the PACU, which was a result of several factors. It is well known that stimulation to PC6 reduces the incidence of PONV, and the reduced intraoperative opioid dose is related to the low incidence of PONV. The reduced incidence of opioid-related side effects is probably related to reduced intraoperative opioid consumption, indicating that 2/100 Hz TEAS has potential benefits as an alternative to general anesthesia, especially among patients susceptible to side effects.

We found that the decrease in PaO_2 during one-lung ventilation was slower in the 2/100 Hz TEAS group than in the control group. In general, PaO_2 gradually decreases during one-lung ventilation because of reduced oxygen-exchange area, V/Q imbalance, and impaired hypoxygenic pulmonary vascular constriction. It has been reported that acupuncture and electro-acupuncture treatment improve lung function and protect against hypoxia-induced pulmonary injury by stimulating Aα and Aβ nerve fibers [9, 30–33]. We believed 2/100 Hz TEAS as an adjuvant anesthetic technique may actually improve oxygenation for patients receiving one-lung ventilation by allowing use of a lower anesthetic dosage, which may have negative effects on oxygenation. However, further studies are needed to investigate whether TEAS treatment is of real benefit to hypoxygenic status during one-lung ventilation.

We observed that, compared with the control group, 100 Hz TEAS treatment significantly reduced the incidence of PONV 48 h after lobectomy. The anti-PONV effects of acupuncture may be attributed to changes in the activity of neurochemicals, including endorphins, serotonin, and norepinephrine, in the central nervous system, which desensitize the vomiting center in the brain, ultimately strengthen the intrinsic anti-vomiting pathway; once the vomiting center in the brain is sensitized, it is difficult to desensitize it [34]. We assumed that high-frequency TEAS initiates release of more neurochemicals at an early stage and immediately desensitizes the vomiting center, because of which 100 Hz had good anti-PONV effects.

In our study, postoperative analgesic dosages were no different among groups, in contrast with a previous study [35]; the reasons may be the limited rounds of TEAS administered after surgery, the relatively small sample size, and the use of multiple medications. Further, the rates of FEV_1 and FVC change were not significantly different among the groups. We assume the lung-protective effect of TEAS does not emerge during lung surgery. In addition, TEAS treatment had no significant effect on nausea and vomiting score at any time, perhaps nausea and vomiting should be considered together. To evaluate the effect of TEAS on patient prognosis, we performed the SF-12 survey to determine health-related quality of life [36, 37]. However, we found no significant difference among the groups; the reasons may be insufficient intervention, incorrect follow-up period, and effect of postoperative chemotherapy for some patients.

Limitations

The sample size in this study was relatively small, and the single-center design is another limitation. Selection bias may have resulted in discrepancies in the measurement indicators. Thus, further studies with several centers and a larger sample size are needed to thoroughly evaluate the efficacy of TEAS in perioperative pain relief, patient recovery, lung protection, and prognosis improvement.

Conclusions

TEAS is a noninvasive and non-pharmacological modality for perioperative analgesia. Among patients undergoing VATS lobectomy, different TEAS frequencies had different effects, including reduced opioid consumption, reduced post-anesthesia recovery time, reduced rate of intraoperative PaO_2 decline, and PONV prevention.

Acknowledgments The authors thank doctors of the thoracic surgery department for cooperating with the clinical trial. This research was supported by grant from the National Basic Research Program of Ministry of Science and Technology of China (2013CB531900)&Peking University People's Hospital R&D fund(RDC2013-09).

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