

Comparison of Postoperative Pain after Different Thoracic Surgery Approaches as Measured by Electrical Stimulation

Norifumi Tsubokawa¹ Hiroaki Harada¹ Chie Takenaka¹ Keizo Misumi¹ Yoshinori Yamashita¹

¹Department of Respiratory Surgery, National Hospital Organization, Kure Medical Center and Chugoku Cancer Center, Kure, Japan

Address for correspondence Yoshinori Yamashita, MD, PhD, Department of Respiratory Surgery, National Hospital Organization, Kure Medical Center and Chugoku Cancer Center, 3-1 Aoyama Cho, Kure City, Hiroshima, 737-0023, Japan (e-mail: yamashitay@kure-nh.go.jp).

Thorac Cardiovasc Surg 2015;63:519–525.

Abstract

Background Postoperative pain is commonly evaluated using the numerous rating scale (NRS), visual analogue scale, or pain scale; however, these assessments are easily affected by various subjective factors. We measured the degree of postoperative chest pain among different thoracic surgery approaches using NRS and electrical stimulation measurements.

Methods Seventy patients who underwent lobectomy or segmentectomy were enrolled. Concomitant with NRS, pain scores were quantitatively measured on postoperative day 2 using an electrical neurostimulator to compare the degree of pain among three different surgical approaches: pure video-assisted thoracic surgery (VATS), hybrid VATS, and conventional thoracotomy. The risk factors associated with postoperative pain were also analyzed.

Results Thirty patients underwent lung resection with pure VATS, while 30 had hybrid VATS, and 10 had conventional thoracotomy. Among the three surgical approaches, analyzing the pain score indicated statistically significant differences (pure, 159.50 ± 26.22 ; hybrid, 269.36 ± 30.49 ; thoracotomy, 589.40 ± 141.11 ; $p = 0.003$); however, NRS did not obtain a statistically significant difference between the three approaches (pure, 4.26 ± 0.27 ; hybrid, 4.96 ± 0.30 ; thoracotomy, 5.50 ± 0.68 ; $p = 0.105$). A multivariate analysis showed that the surgical approach was an independent risk factor for postoperative pain as determined by the pain score (pure vs. hybrid, $p = 0.076$; pure vs. thoracotomy, $p < 0.001$).

Conclusion For lung surgery, the differences in surgical approach were an independent risk factor for postoperative pain. In the early postoperative period, pure VATS was shown to be the least painful of the three surgical approaches.

Keywords

- ▶ surgery
- ▶ complications
- ▶ video-assisted thoracic surgery
- ▶ postoperative care

Introduction

Endoscopic surgery is a less invasive approach than conventional surgery that reduces postoperative pain.¹ Video-assisted thoracic surgery (VATS) has been widely performed to treat lung cancer.¹ Several technical approaches, including pure VATS and hybrid VATS, have been applied depending on the

facilities and surgeons¹; however, a few reports have evaluated the differences in postoperative pain between pure and hybrid VATS approaches.

Postoperative pain is commonly evaluated in a subjective manner by assessments, such as the numerous rating scale (NRS), visual analogue scale, or pain scale. While these assessments are convenient and widely used, they have an

received
August 7, 2014
accepted after revision
December 10, 2014
published online
March 13, 2015

© 2015 Georg Thieme Verlag KG
Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0035-1546427>.
ISSN 0171-6425.

upper limit regarding the pain scale, and the outcomes are easily affected by race, sex, age, psychological factors, and other factors.² Therefore, considerable individual variation exists regarding the evaluative criteria for pain, making comparisons with other individuals difficult. In addition, it is uncertain whether the surgical approach is the only cause of postoperative pain; various factors, such as the type of drain and operating time, may also be associated with postoperative pain.

To address some of these questions, using electrical stimulation (Pain Vision, Nipro, Osaka, Japan), a pain score was used to quantitatively measure postoperative pain, so as to determine the magnitude of pain in a new way, involving painless electrical stimulation without an upper pain scale limit. Electrical stimulation is not easily influenced by other factors and can measure pain more accurately than conventional tools. In addition, previous studies have shown that electrical stimulation is useful for the quantitative evaluation of sensory nerve fibers associated with postoperative chest pain,² diabetic neuropathy,³ postherpetic neuralgia,⁴ peripheral nerve injury,⁵ lumbar radiculopathy,⁶ and chronic sciatica.⁷ In this study, we compared the degree of postoperative chest pain among different surgical approaches, including two types of VATS, and investigated the risk factors for postoperative pain.

Patients and Methods

Ethics Statement

This study was approved by the National Hospital Organization Kure Medical Center and Chugoku Cancer Center Institutional Review Board Ethics Committee (approval number: 23-46) that waived the requirement for the provision of written informed consent from individual patients.

Study Population and Surgical Procedures

Between June 2010 and May 2013, 80 patients underwent lobectomy or segmentectomy via one of the three different surgical approaches. The parameters for each approach were precisely defined. Pure VATS was performed via a 3 to 4 cm access thoracotomy without a rib retractor. During this type of surgery, the operative field of view was strictly accessed via a single monitor without enlarging the intercostal space to reduce operative stress on the chest wall. Three other 0.5 to 1.0 cm ports were used for assistance and scope.^{1,8} Hybrid VATS was performed via a 6 to 8 cm anterolateral muscle-sparing small thoracotomy without a rib retractor. The intercostal muscle was dissected almost the same length as for conventional thoracotomy. This type of surgery was performed using both television monitoring and direct visualization that uses the thoracoscope as a light source.⁹ Conventional thoracotomy group was performed via a > 8 cm skin incision in an anterolateral thoracotomy using a rib spreader. The latissimus dorsi was partly divided, if necessary, and the serratus anterior muscle was split.

In addition, regarding closure of the thoracotomy, the procedure was different for each approach. For pure VATS

and hybrid VATS, the access thoracotomy was closed without suturing of ribs; however, for conventional thoracotomy, both sides of the ribs were sutured together to narrow the intercostal space.

The surgical approach was chosen using the following criteria: pure VATS was performed for patients with a small-sized lung cancer (tumor size < 30 mm) but without any clinical lymph node metastases; conventional thoracotomy was performed for patients requiring complicated procedures for treating locally advanced lung cancer; hybrid VATS was performed for patients with other types of lung cancer or those requiring segmentectomy. Patients who underwent wedge resection were excluded because most wedge resections were performed via pure VATS, giving the potential for bias. In addition, patients who underwent pneumonectomy or extended resections (e.g., chest wall resection) were also excluded because these procedures often require larger incisions and further invasiveness.

In our institution at the time, Blake drain (Ethicon, Somerville, NJ) was our standard instrument for chest drainage; however, for patients with a high risk of postoperative air leakage or hemorrhage, a flat type drain (Sumitomo Bakelite, Tokyo, Japan) was preferred.

Management of Postoperative Pain

All patients were administered with a continuous infusion of 0.2% ropivacaine (200 mL) plus fentanyl (300 µg) through a patient-controlled epidural analgesia pump after surgery until postoperative day (POD) 2. The epidural analgesia was stopped in 29 patients on POD 1 because they developed adverse effects such as nausea, vomiting or low blood pressure (12 [36%], 12 [34%] and 5 [41%] in the pure VATS, hybrid VATS, and thoracotomy groups, respectively). In addition, all patients were administered with a nonsteroid anti-inflammatory drug from POD 1, and pregabalin or tramadol was added as required after pain assessment.

Measurement Procedure of Postoperative Pain

The degree of postoperative pain was evaluated by NRS and the pain score was determined by electrical stimulation. The NRS is more frequently applied in clinical practice as it is an established, reliable, and valid measure of pain intensity.¹⁰⁻¹² For the NRS, the patients rated their pain on a scale of 0 to 10 either verbally or by placing a mark on a line indicating their level of pain. Zero indicated the absence of pain, while 10 represented the most intense pain possible.

Electrical stimulation delivers a sinusoidal constant alternating current (50 Hz; 0-250 µA, pulse width, 0.5 milliseconds). To eliminate individual differences resulting from factors, such as contact with electrodes, skin conditions, and sensory nerve distribution, different types of current perception thresholds (CPT) were measured. The first was the minimum perception threshold (MPT), at which a patient starts to perceive the current applied to a normal forearm. The second was the pain equivalent threshold (PET), which is the current threshold that a



Fig. 1 Pain Vision (arrow) was used to measure postoperative chest pain by assessing current perception threshold (CPT) on POD 2.

patient perceives as equivalent in strength that of the postoperative pain, causing the patient to worry. The pain score was calculated as follows: $(PET - MPT) / MPT$. If no pain existed, this value was 1 and increased with the degree of pain, without an upper limit.

Concomitant with the NRS, the pain score was measured on POD 2. As the degree of postoperative pain needs to be assessed under identical condition, we stopped the administration of analgesic medications 8 hours and epidural anesthesia 2 hours before the measurement, and a single chest drainage tube was placed for all patients (**►Fig. 1**). Patients who used analgesic medications because of the unbearable pain on POD 2, 8 hours after stopping administration of analgesic medications and 2 hours after stopping epidural anesthesia, were excluded because each score might have been underestimated. The pain score and NRS were compared among pure VATS, hybrid VATS, and conventional thoracotomy. In addition, the risk factors related to postoperative pain as determined by the pain score were also analyzed.

Statistical Analysis

Data were summarized and are presented as numbers, median (25–75% interval), or means \pm standard deviation. Categorical variables were compared using the χ^2 test. Continuous variables were compared using the two tests: the Kruskal–Wallis test is for comparison of two independent groups and the Mann–Whitney *U* test is for comparing three independent groups. Variables that had a *p* value of < 0.2 upon a univariate analysis were considered for a multivariate linear regression for pain score to identify the risk factors for postoperative

pain. Data were analyzed using JMP statistics software (Version 9.0, SAS Institute, Inc., Cary, NC, USA).

Results

Of the 80 patients, 33 underwent pure VATS, 35 underwent hybrid VATS, and 12 underwent conventional thoracotomy. In this study, no patients converted from VATS approach to conventional thoracotomy. For those patients who used analgesic medications because of the unbearable pain on POD 2, 8 hours after stopping administration of analgesic medications and 2 hours after stopping epidural anesthesia, the NRS and pain score were not measured; these patients included 3 (9.1%) for pure VATS, 5 (14.3%) for hybrid VATS, and 2 (16.7%) for conventional thoracotomy. A total of 70 patients had their postoperative pain measured using the NRS and pain score. The characteristics of 70 patients are summarized in **►Table 1**. More females underwent pure VATS than the other two surgical procedures. Flat drains were used more frequently for patients undergoing conventional thoracotomy.

The median pain score measured by electrical stimulation was 202 (25–75% interval, 87–368). The median NRS was 5.0 (25–75% interval, 4–9). Regarding the pain score, a statistically significant difference among the three surgical approaches was revealed (pure VATS, 159.50 ± 26.22 ; hybrid VATS, 269.36 ± 30.49 ; conventional thoracotomy, 589.40 ± 141.11 ; $p = 0.003$) (**►Fig. 2A**). Differences in NRS among the three approaches did not reach statistical significance (pure VATS, 4.26 ± 0.27 ; hybrid VATS, 4.96 ± 0.30 ; conventional thoracotomy, 5.50 ± 0.68 ; $p = 0.105$) (**►Fig. 2B**).

Table 1 Patient characteristics

	Pure	Hybrid	Thoracotomy	p-Value
	n = 30 (%)	n = 30 (%)	n = 10 (%)	
Age \geq 70	14 (46.7)	13 (43.3)	4 (40)	1
Sex				0.925
Male	16 (53.3)	22 (73.3)	7 (70)	
Female	14 (46.7)	8 (26.7)	3 (30)	
Presence of diabetes	4 (13.3)	3 (10)	2 (20)	0.711
Pathological diagnosis				< 0.001
Adenocarcinoma	25 (83.3)	20 (66.7)	2 (20)	
Squamous carcinoma	2 (6.7)	6 (20)	8 (80)	
Others	3 (10.0)	4 (13.3)	0 (0)	
Surgical procedure				0.015
Lobectomy	28 (93.3)	21 (70)	10 (100)	
Segmentectomy	2 (6.7)	9 (30)	0	
Type of drain				< 0.001
Blake drain	28 (93.3)	22 (73.3)	3 (30)	
Flat drain	2 (6.7)	8 (26.7)	7 (70)	
Operating time > 180 min	23 (76.7)	19 (63.3)	8 (80)	0.421

The pain score tended to be higher for patients who were older, were female, had hybrid VATS, had conventional thoracotomy, had segmentectomy, or were using flat drains (as compared with Blake drains); in contrast, the NRS did not significantly differ for differences among these parameters (**Table 2**). A multivariate linear regression for pain score analysis is summarized in **Table 3**. The model intercept of estimated regression coefficient was 25.04. Adjusted R-squared was 0.308. Open thoracotomy was a significant independent risk factor for postoperative pain ($p < 0.001$) (**Table 3**). In addition, pure VATS tended to result in lower postoperative chest pain than hybrid VATS ($p = 0.076$).

Discussion

This study showed that postoperative chest pain after pure VATS was the lowest of the three different surgical approaches as assessed by electrical stimulation, whereas assessment by NRS did not reveal statistically significant differences among the three approaches. In addition, the surgical approach was a significant independent risk factor for postoperative pain. Of the two VATS methods, although a statistically significant difference was not detected, postoperative chest pain tended to be lower for patients who underwent pure VATS than in hybrid VATS.

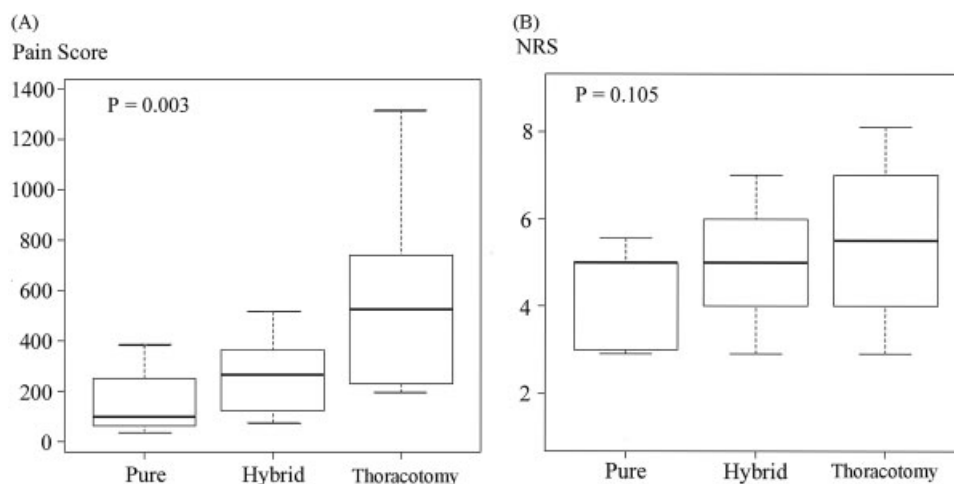
**Fig. 2** The relationship among the pain score (A), NRS (B), and surgical approaches.

Table 2 Univariate analysis for risk factors of postoperative chest pain

Factors	NRS ^a	p Value	Pain score ^b	p-Value
Age		0.971		0.094
< 70	4.67 ± 1.71		276.70 ± 28.56	
≥ 70	4.82 ± 1.75		257.83 ± 60.19	
Sex		0.315		0.098
Male	4.58 ± 1.88		255.55 ± 43.39	
Female	5.02 ± 1.35		290.40 ± 37.36	
Diabetes		0.469		0.544
Yes	4.22 ± 1.92		301.67 ± 69.47	
No	4.81 ± 1.69		263.03 ± 33.98	
Side		0.922		0.436
Right	4.72 ± 1.77		287.76 ± 59.78	
Left	4.76 ± 1.66		263.03 ± 31.69	
Surgical approach		0.105		< 0.001
Pure VATS	4.26 ± 1.48		159.50 ± 26.22	
Hybrid VATS	4.96 ± 1.69		269.36 ± 30.49	
Conventional thoracotomy	5.50 ± 2.17		589.40 ± 141.11	
Surgical procedure		0.474		0.032
Lobectomy	5.09 ± 1.22		272.04 ± 35.41	
Segmentectomy	4.67 ± 1.79		341.72 ± 44.89	
Type of drain		0.904		0.007
Blake drain	4.69 ± 1.60		214.73 ± 24.95	
Flat drain	4.88 ± 2.08		434.05 ± 90.93	
Operating time		0.391		0.160
< 180 min	4.42 ± 1.63		196.75 ± 41.17	
≥ 180 min	4.87 ± 1.75		296.50 ± 39.37	
Amount of blood loss		0.513		0.985
< 100 g	4.59 ± 1.72		241.61 ± 30.87	
≥ 100 g	4.89 ± 1.72		295.94 ± 54.49	

Abbreviation: NRS, numerous rating scale; VATS, video-assisted thoracic surgery.

^aNumerous rating scale.

^bPostoperative chest pain measured using electrical stimulation.

Previous reports have shown that VATS contributed to a reduction in postoperative pain,^{1,13–17} which is consistent with the results of our study. In addition, the proportion of patients who were excluded from the NRS and pain score assessments in this study because of the administration of analgesics for intolerable pain was lowest for pure VATS among the three approaches, indicating that postoperative chest pain with pure VATS was lower than that with the other approaches. These findings might be explained by differing degrees of intercostal nerve injury that depends on the length of the intercostal muscle dissection and the rib retractor use. The difference in postoperative pain between patients who underwent the hybrid and pure VATS is explained by the larger intercostal muscle resection with hybrid VATS. The preservation of the intercostal nerves has been shown to reduce postoperative pain.^{18,19} Differential use of a rib retractor could

also account for differences in postoperative pain among the different surgical approaches. Further, several reports have shown that the use of a rib retractor induces intercostal nerve damage because of direct ischemic injury and stretch injury, causing post-thoracotomy pain.^{2,20,21}

Electrical stimulation can evaluate sensory nerve fibers quantitatively and selectively.² This method was applied for measuring pain associated with diabetic neuropathy³ and chronic sciatica,⁷ showing that the Aβ and Aδ fibers play a significant role in the development of intercostal nerve damage.² In the same way, the pain score can also help quantify peripheral nerve dysfunction by measuring detection thresholds for constant current stimulation. The sensitivity of this instrument revealed a statistically significant difference in postoperative pain between the three surgical approaches. The NRS did not significantly differ among the

Table 3 Multivariate linear regression analysis for the risk factors of postoperative pain measured by pain score

Factors	Estimated regression coefficient	95% CI	p-Value
Age			
< 70 y	reference		
≥ 70 y	13.74	−97.67 to 125.16	0.806
Sex			
Male	reference		
Female	85.63	−27.99 to 199.25	0.137
Surgical approach			
Pure VATS	reference		
Hybrid VATS	113.37	−2.45 to 239.20	0.076
Conventional thoracotomy	427.91	241.28 to 614.53	< 0.001
Surgical procedure			
Lobectomy	reference		
Segmentectomy	92.88	−62.30 to 248.07	0.236
Type of drain			
Blake drain	reference		
Flat drain	31.42	−122.71 to 185.55	0.685
Operating time			
< 180 min	reference		
≥ 180 min	104.09	−25.83 to 234.00	0.114

Abbreviations: CI, confidence interval; VATS, video-assisted thoracic surgery.

three approaches. In addition, the NRS of the VATS groups was relatively higher in this study, than in the previous studies,^{13,22} perhaps because of the following reasons. Postoperative pain was assessed after stopping pain therapy including epidural anesthesia, whereas such pain was evaluated without stopping pain therapy in previous studies. Obtaining reliable results from the small sample of patients in this study was difficult because various factors affected the NRS. In fact, this conclusion should be interpreted with care considering that the power and required sample size for NRS were 0.53 and 132, respectively. As previous studies have found that NRS assessments of pain significantly differ among surgical approaches,^{13–16} the difference in NRS might reach significance with a larger patient cohort in this study.

Our study demonstrated that the surgical approach was a significant independent risk factor for postoperative chest pain as determined by the pain score. These findings also indicate that early postoperative chest pain was largely attributed to intercostal nerve damage. Although several investigators have evaluated the differences in postoperative chest pain among approaches,^{13–17} postoperative pain might be affected not just by the surgical approach but also by other factors such as age, sex, surgical procedure, operating time, or drain type. This study revealed that these factors were not independent risk factors for postoperative chest pain. As the pain score measured the minimum electrical stimulation that patients sense as pain, individual differences in pain

sensation caused by factors, such as age or sex, may not have confounded the results.

In this study, we measured postoperative pain only on POD 2 when all patients had a chest drainage tube because we routinely removed the chest drains after POD 2; therefore, the degree of postoperative pain was assessed under identical conditions for all eligible patients. In addition, epidural analgesia, which is known to be one of the most effective methods for pain control after thoracic surgery,^{23–25} was generally ceased on POD 2. We considered that an assessment of postoperative pain on POD 2 was important for clinical outcomes. If postoperative pain is severe during this period, effective coughing, deep breathing, and movement can be inhibited, which could lead to delayed recovery after surgery.

This study had several limitations. While the data were prospectively collected, this study was not a randomized trial. As the surgeons conducted the chest pain measurements, this study was not blinded; therefore, this might have led to a potential bias in this study. The number of patients was small and differed among the groups. Since the patients decided on the use of analgesic medications, this study depended partly on the patient choice, so the statistical accuracy might be weak. Moreover, this study did not evaluate pain in the late postoperative period, complications, or the duration of hospital stays. However, none of the patients had a prolonged hospital stay because of uncontrollable chest pain.

In summary, the results of this study indicate that the surgical approach used in lung cancer treatment was an independent risk factor for postoperative chest pain. Patients who had undergone pure VATS experienced the least pain on POD 2. Although, additional studies with larger number of patients that include analyses on other postoperative days and the relationship between the degree of postoperative pain and complications are necessitated to evaluate clinical differences in surgical invasiveness among different surgical approaches; these findings can help in the management of postoperative pain after thoracic surgery.

Conflicts of Interest

All authors declare no conflicts of interest.

Funding

This study was supported by the Japanese Foundation for Research and Promotion of Endoscopy. The funders had no role in study design, data collection and analysis, decision to publish, or manuscript preparation.

References

- 1 Yamashita Y, Mukaida H, Harada H, Tsubokawa N. Post-thoracotomy pain and long-term survival associated with video-assisted thoracic surgery lobectomy methods for clinical T1N0 lung cancer: a patient-oriented, prospective cohort study. *Eur J Cardiothorac Surg* 2013;44(1):e71–e76
- 2 Miyazaki T, Sakai T, Tsuchiya T, et al. Assessment and follow-up of intercostal nerve damage after video-assisted thoracic surgery. *Eur J Cardiothorac Surg* 2011;39(6):1033–1039
- 3 Masson EA, Boulton AJ. The Neurometer: validation and comparison with conventional tests for diabetic neuropathy. *Diabet Med* 1991;8(Spec No):S63–S66
- 4 Sakai T, Tomiyasu S, Yamada H, Sumikawa K. Evaluation of allodynia and pain associated with posttherapeutic neuralgia using current perception threshold testing. *Clin J Pain* 2006;22(4):359–362
- 5 Wallace MS, Dyck JB, Rossi SS, Yaksh TL. Computer-controlled lidocaine infusion for the evaluation of neuropathic pain after peripheral nerve injury. *Pain* 1996;66(1):69–77
- 6 Yamashita T, Kanaya K, Sekine M, Takebayashi T, Kawaguchi S, Katahira G. A quantitative analysis of sensory function in lumbar radiculopathy using current perception threshold testing. *Spine* 2002;27(14):1567–1570
- 7 Sakai T, Aoki H, Hojo M, Takada M, Murata H, Sumikawa K. Adhesiolysis and targeted steroid/local anesthetic injection during epiduroscopy alleviates pain and reduces sensory nerve dysfunction in patients with chronic sciatica. *J Anesth* 2008;22(3):242–247
- 8 Shiraishi T, Shirakusa T, Iwasaki A, Hiratsuka M, Yamamoto S, Kawahara K. Video-assisted thoracoscopic surgery (VATS) segmentectomy for small peripheral lung cancer tumors: intermediate results. *Surg Endosc* 2004;18(11):1657–1662
- 9 Okada M, Sakamoto T, Yuki T, Mimura T, Miyoshi K, Tsubota N. Hybrid surgical approach of video-assisted minithoracotomy for lung cancer: significance of direct visualization on quality of surgery. *Chest* 2005;128(4):2696–2701
- 10 Herr KA, Spratt K, Mobily PR, Richardson G. Pain intensity assessment in older adults: use of experimental pain to compare psychometric properties and usability of selected pain scales with younger adults. *Clin J Pain* 2004;20(4):207–219
- 11 Herr K, Spratt KF, Garand L, Li L. Evaluation of the Iowa pain thermometer and other selected pain intensity scales in younger and older adult cohorts using controlled clinical pain: a preliminary study. *Pain Med* 2007;8(7):585–600
- 12 Gagliese L, Weizblit N, Ellis W, Chan VW. The measurement of postoperative pain: a comparison of intensity scales in younger and older surgical patients. *Pain* 2005;117(3):412–420
- 13 Demmy TL, Nwogu C. Is video-assisted thoracic surgery lobectomy better? Quality of life considerations. *Ann Thorac Surg* 2008;85(2):S719–S728
- 14 Roviato G, Varoli F, Vergani C, Maciocco M, Nucca O, Pagano C. Video-assisted thoracoscopic major pulmonary resections: technical aspects, personal series of 259 patients, and review of the literature. *Surg Endosc* 2004;18(11):1551–1558
- 15 Landreneau RJ, Mack MJ, Hazelrigg SR, et al. Prevalence of chronic pain after pulmonary resection by thoracotomy or video-assisted thoracic surgery. *J Thorac Cardiovasc Surg* 1994;107(4):1079–1085, discussion 1085–1086
- 16 Nomori H, Horio H, Naruke T, Suemasu K. What is the advantage of a thoracoscopic lobectomy over a limited thoracotomy procedure for lung cancer surgery? *Ann Thorac Surg* 2001;72(3):879–884
- 17 Sugiura H, Morikawa T, Kaji M, Sasamura Y, Kondo S, Katoh H. Long-term benefits for the quality of life after video-assisted thoracoscopic lobectomy in patients with lung cancer. *Surg Laparosc Endosc Percutan Tech* 1999;9(6):403–408
- 18 Koop O, Gries A, Eckert S, et al. The role of intercostal nerve preservation in pain control after thoracotomy. *Eur J Cardiothorac Surg* 2013;43(4):808–812
- 19 Cerfolio RJ, Bryant AS, Mascalco LM. A nondivided intercostal muscle flap further reduces pain of thoracotomy: a prospective randomized trial. *Ann Thorac Surg* 2008;85(6):1901–1906, discussion 1906–1907
- 20 Rogers ML, Henderson L, Mahajan RP, Duffy JP. Preliminary findings in the neurophysiological assessment of intercostal nerve injury during thoracotomy. *Eur J Cardiothorac Surg* 2002;21(2):298–301
- 21 Swanson SJ, Herndon JE II, D'Amico TA, et al. Video-assisted thoracic surgery lobectomy: report of CALGB 39802—a prospective, multi-institution feasibility study. *J Clin Oncol* 2007;25(31):4993–4997
- 22 Wildgaard K, Petersen RH, Hansen HJ, Møller-Sørensen H, Ringsted TK, Kehlet H. Multimodal analgesic treatment in video-assisted thoracic surgery lobectomy using an intraoperative intercostal catheter. *Eur J Cardiothorac Surg* 2012;41(5):1072–1077
- 23 Gottschalk A, Cohen SP, Yang S, Ochroch EA. Preventing and treating pain after thoracic surgery. *Anesthesiology* 2006;104(3):594–600
- 24 Soto RG, Fu ES. Acute pain management for patients undergoing thoracotomy. *Ann Thorac Surg* 2003;75(4):1349–1357
- 25 Ochroch EA, Gottschalk A. Impact of acute pain and its management for thoracic surgical patients. *Thorac Surg Clin* 2005;15(1):105–121