Expert consensus on spontaneous ventilation video-assisted thoracoscopic surgery in primary spontaneous pneumothorax (Guangzhou)

Jianxing He[1,2,3,4,5], Jun Liu[1,2,3,4,5], Chengchu Zhu[6], Tianyang Dai[7], Kaican Cai[8], Zhifeng Zhang[9], Chao Cheng[10], Kun Qiao[11], Xiang Liu[12], Guangsuo Wang[13], Shun Xu[14], Rusong Yang[15], Junqiang Fan[16], Hecheng Li[17], Jiang Jin[6], Qinglong Dong[1,2,3,4,5], Lixia Liang[1,2,3,4,5], Jinfeng Ding[18], Kaiming He[7], Yulin Liu[19], Jing Ye[20], Siyang Feng[8], Yu Jiang[21], Haoda Huang[9], Huankai Zhang[22], Zhenguo Liu[10], Xia Feng[23], Zhaohua Xia[11], Mingfei Ma[24], Zhongxin Duan[25], Tonghai Huang[13], Yali Li[26], Qiming Shen[14], Wenfei Tan[14], Hong Ma[27], Yang Sun[28], Congcong Chen[29], Fei Cui[1,2,3,4,5], Wei Wang[1,2,3,4,5], Jingpei Li[1,2,3,4,5], Zhexue Hao[1,2,3,4,5], Hui Liu[1,2,3,4,5], Wenhua Liang[1,2,3,4,5], Xusen Zou[1,2,3,4,5], Hengrui Liang[1,2,3,4,5], Hanyu Yang[1,2,3,4,5], Yingfen Li[1,2,3,4,5], Shunjun Jiang[1,2,3,4,5], Calvin S. H. Ng[30], Diego González-Rivas[31], Eugenio Pompeo[32], Raja M. Flores[33], Yaron Shargall[34], Mahmoud Ismail[35], Benedetta Bedetti[36], Ahmed G. Elkhouly[37], Keng Ang[38]

[1]National Clinical Research Center for Respiratory Disease, Guangzhou 510120, China; [2]First Affiliated Hospital of Guangzhou Medical University, Guangzhou 510120, China; [3]Guangzhou Institute of Respiratory Health, Guangzhou 510120, China; [4]China State Key Laboratory of Respiratory Disease, Guangzhou 510120, China; [5]National Clinical Research Center for Respiratory Disease, Guangzhou 510120, China; [6]Department of Thoracic Surgery, Taizhou Hospital, Taizhou 318000, China; [7]Department of Thoracic Surgery, Southwest Medical University Affiliated Hospital, Luzhou 646000, China; [8]Department of Thoracic Surgery, Nanfang Hospital of Southern Medical University, Guangzhou 510120, China; [9]Department of Thoracic Surgery, Jieyang People's Hospital, Jieyang 522000, China; [10]Department of Thoracic Surgery, First Affiliated Hospital of Sun Yat-sen University, Guangzhou 510120, China; [11]Department of Thoracic Surgery, Third People's Hospital of Shenzhen, Shenzhen 518000, China; [12]Department of Thoracic Surgery, Second Affiliated Hospital of the University of South China, Hengyang 420100, China; [13]Department of Thoracic Surgery, People's Hospital of Shenzhen, Shenzhen 518000, China; [14]Department of Thoracic Surgery, First Affiliated Hospital of China Medical University, Shenyang 110000, China; [15]Department of Thoracic Surgery, Nanjing Chest Hospital, Nanjing 210000, China; [16]Department of Thoracic Surgery, Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou 310000, China; [17]Department of Thoracic Surgery, Ruijin Hospital Affiliated to Shanghai Jiaotong University School of Medicine, Shanghai 200000, China; [18]Department of Anesthesia, Taizhou Hospital, Taizhou 318000, China; [19]Department of Anesthesia, Southwest Medical University Affiliated Hospital, Luzhou 646000, China; [20]Department of Anesthesia, Nanfang Hospital of Southern Medical University, Guangzhou 510120, China; [21]Department of Anesthesia, Nanfang Hospital of Southern Medical University, Guangzhou 510120, China; [22]Department of Anesthesia, Jieyang People's Hospital, Jieyang 522000, China; [23]Department of Anesthesia, First Affiliated Hospital of Sun Yat-sen University, Guangzhou 510120, China; [24]Department of Anesthesia, Third People's Hospital of Shenzhen, Shenzhen 518000, China; [25]Department of Anesthesia, Second Affiliated Hospital of the University of South China, Guangzhou 510120, China; [26]Department of Anesthesia, People's Hospital of Shenzhen, Shenzhen 518000, China; [27]Department of Anesthesia, First Affiliated Hospital of China Medical University, Shenyang 110000, China; [28]Department of Anesthesia, Nanjing Chest Hospital, Nanjing 210000, China; [29]Department of Anesthesia, Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou 310000, China; [30]Division of Cardiothoracic Surgery, Department of Surgery, The Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong SAR, China; [31]Department of Thoracic Surgery, Coruña University Hospital, Coruña, Spain; [32]Department of Thoracic Surgery, Policlinico Tor Vergata University, Rome, Italy; [33]Department of Thoracic Surgery, Mount Sinai Health System, Icahn School of Medicine at Mount Sinai, New York, NY, USA; [34]Division of Thoracic Surgery, McMaster University, St. Joseph's Healthcare, Hamilton, Canada; [35]Department of Thoracic Surgery, Klinikum Ernst von Bergmann, Academic Hospital of the Charité - Universitätsmedizin Humboldt University Berlin, Potsdam Germany; [36]Department of Thoracic Surgery, Malteser Hospital, Bonn, Germany; [37]Department of Cardiothoracic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt; [38]Department of Thoracic Surgery, Nottingham City Hospital and Glenfield Hospital, Leicester, UK

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Correspondence to: Jianxing He. Department of Thoracic Surgery and Oncology, The First Affiliated Hospital of Guangzhou Medical University, Guangzhou 510120, China; State Key Laboratory of Respiratory Disease, Guangzhou 510120, China; National Clinical Research Center for Respiratory Disease, Guangzhou 510120, China; Guangzhou Institute of Respiratory Health, Guangzhou 510120, China.
Email: drjianxing.he@gmail.com.

Introduction

Primary spontaneous pneumothorax (PSP) has an estimated incidence ranging from 17–24/100,000 and 1–6/100,000 among males and females, respectively (1,2). It usually occurs in tall thin individuals between 10–30 years of age, especially smokers (3). Common symptoms include chest pain and mild dyspnea (4). Besides, PSP is highly recurrent with rates ranging from 17% to 54% within 1–6 years (2). In particular, patients can experience contralateral PSP with a reported rate ranging from 5% up to 27% with the highest rates reported in patients with contralateral bullae at the high-resolution-computed-tomography (HRCT) scans (5). HRCT has shown that more than 50% of patients with unilateral PSP have pulmonary bullae in the contralateral lung (6). Surgical treatment of PSP is indicated in patients with recurrent or persistent lung collapse, hemopneumothorax, bilateral pneumothorax, and/or failed clinical observation or conservative treatment with simple thoracic drainage (7). Several studies have suggested the superiority of video-assisted thoracoscopic surgery (VATS) over a thoracotomy in the treatment of PSP due to lower postoperative pain and morbidity, and shorter hospital stay (8-11).

With the advances in VATS and novel anesthesia protocols, spontaneous ventilation VATS (SV-VATS) has been increasingly employed (12). Traditionally, VATS is performed under general anesthesia using a double-lumen endotracheal tube and single-lung mechanical ventilation (11,12). Although this approach provides a relatively good surgical view and static operative field for optimal surgical maneuvering, mechanical ventilation, and the use of muscle relaxants during endotracheal intubation can potentially induce adverse effects in various organs/systems (13). For instance, mechanical ventilation may lead to lung overexpansion and pressure-induced airway injuries, while endotracheal intubation can also cause damage to the mucosa of the upper respiratory tract, as well as being associated with barotrayma caused by pro-inflammatory mediators (14,15). Compared with tracheal intubation,

non-intubated spontaneous breathing-based anesthesia has advantage that patients can preserve spontaneous breathing during surgery; intravenous sedatives/analgesics, local infiltration anesthesia, and nerve block could be used and artificial pneumothorax would be established to facilitate surgical maneuvering. At present, SV-VATS for PSP is deemed to avoid the residual effect of muscle relaxants, lower the incidences of perioperative complications, preserve the functions of respiratory muscles after surgery, and speed up postoperative recovery (16).

In 1997, Nezu *et al.* (17) were the first to treat PSP with SV-VATS bullectomy, with satisfactory results. In 2007, Pompeo *et al.* (18). reported that SV-VATS bullectomy under thoracic epidural anesthesia shortened hospital stay and achieved better patient satisfaction. Since 2011, the First Affiliated Hospital of Guangzhou Medical University has advocated and promoted SV-VATS in China (13). In 2016, the center described the application of tubeless VATS bullectomy (19), and adoption of SV-VATS significantly shortened postoperative fasting and average postoperative hospital stay, alleviated postoperative pain, thereby accelerating postoperative recovery (20).

So far, SV-VATS has been successfully and increasingly applied in thoracic surgery worldwide, from wedge resection and sympathectomy to myasthenia gravis and tracheal reconstruction (9,10,21-30). SV-VATS bullectomy has been adopted with satisfactory results in China as well as in other countries worldwide (9,13,24). However, in the face of a large literature with a low level of retrospective evidence, there is a need for some standardization about SV-VATS. The following document is a resulting expert consensus, summarizing the relevant technical points to facilitate a wider application of these surgical and anesthesia methods.

Indications

The panel of this document suggests that the indications

for SV-VATS do not differ from those required for standard intubated VATS. That is, most patients with recurrent PSP and/or with radiologic evidence of clear bullae, which are also commonly defined emphysematous-like-changes or blebs, at the HRCT, are eligible for surgical treatment.

In addition to the clinical/radiological findings, other eligibility criteria include:

(I) Patient is agreeable to the surgery and anesthesia protocols and is cognitively competent to sign an informed consent form or, if aged <18 years, the parents express their informed consent for the operation.

(II) The patient has an Eastern Cooperative Oncology Group (ECOG) physical performance score of ≤1 point.

(III) The patient has an American Society of Anesthesiologists Standard (ASA) grade of ≤II.

(IV) The patient has cardiopulmonary and other vital organs functions which do not contraindicate surgical treatment

Exclusion criteria

(I) Patient-related factors: (i) patient refusal to the surgery and anesthesia protocols; (ii) history of surgery in the ipsilateral thoracic cavity; (iii) associated severe acute pulmonary infection and/or tuberculosis; (iv) obesity with a body mass index (BMI) >30; (v) allergy to local anesthesia; (vi) coagulopathy; elevated risk of regurgitation (<6 hours of fasting); (vii) hypoxemia (PaO_2 <60 mmHg) or hypercapnia ($PaCO_2$ >50 mmHg) preoperatively; neurological disorders. Relative contraindications are persistent cough or high airways secretions; spinal deformity or brain edema.

(II) Anesthesiologist-related factors: any contraindications for the use of regional anesthesia technique; difficult airway management.

(III) Surgeon-related factors: extensive pleural adhesions; insufficient experience of surgeon and/or anesthetist. Previous ipsilateral surgery.

Preoperative management

Preoperative assessment

(I) Clinical assessment: collection of demographics and accurate patient's clinical history including a description of previous and present illnesses. Assess should focus on patients' need for surgery and

suitability for SV-VATS.

(II) Laboratory tests: routine blood tests; testing for blood type, liver function, kidney function, electrolytes, and coagulation function; arterial blood gas analysis; testing for hepatitis B virus, hepatitis C antibody, and routine urine tests.

(III) Electrocardiogram (ECG) and in selected patients with suspected cardiac conditions, cardiac echocardiogram should be performed pre-operatively.

(IV) Chest X-ray (anterior-posterior/lateral views) or HRCT scan at the discretion of the operating surgeon.

Antibacterial prophylaxis

A regular dose of a second-generation cephalosporin is intravenously administered 30 minutes to 1 hour prior to the operation. The duration and times depend on the antibiotic used and institution. The dose may be adjusted in patients with renal dysfunction. No antibiotics are usually employed after 48 hours unless the patient develops an acute bacterial infection

Anesthesia

Used anesthesia methods

Intravenous anesthesia assisted by local intercostal nerve block is today the most commonly used anesthesia protocol for this surgical procedure. Alternative anesthesia methods to be employed in centers with specific expertise include thoracic epidural analgesia as well as the following integrated protocols:

(I) Intravenous anesthesia + laryngeal mask airway (LMA) + thoracic paravertebral block (TPVB) + visceral pleural surface anesthesia + thoracic vagus nerve block on the operated side.

(II) Intravenous anesthesia + LMA + intercostal nerve block + visceral pleural surface anesthesia + thoracic vagus nerve block on the operated side.

❖ Nasal cannula or facial mask can be used as an alternative to LMA in some patients.

TPVB or intercostal nerve block

TPVB guided by ultrasound is performed at two points on the surgical side, T5–6, and T7–8; 10 mL of 0.375% ropivacaine is injected at each point.

Under VATS, an intercostal nerve block is performed at

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multiple points from the T2 to T8; A 1 mL mixture of 0.75% ropivacaine and 2% lidocaine (1:1) is injected at each point.

Visceral pleural surface anesthesia

After the thoracic cavity is entered, 5–10 mL of 2% lidocaine is sprayed on the visceral pleural surface.

Vagus nerve block on the surgical site

The vagus nerve on the surgical site is blocked with a 2.5 mL mixture of 0.75% ropivacaine and 2% lidocaine. During the vagus nerve block, the right side is blocked on the surface of the trachea above the azygos arch, and the left side is blocked on the surface of the ascending aorta above the lung root (under the mediastinal pleura).

Preparation before anesthesia

After the patient enters the operating room, the electrocardiogram (ECG), heart rate (HR), blood pressure (Bp), pulse oxygen saturation (SpO_2), and respiratory rate (RR) is constantly monitored. The radial artery is punctured and cannulated at the non-surgical side for continuous monitoring of blood pressure (IBP) and periodic monitoring of blood gases. Placement of deep venous catheters and urinary catheterization is seldom required.

Stages of anesthesia

(I)   Pre-anesthesia medication: Atropine 0.01 mg/kg is intravenously administered before anesthesia (use with caution in patients with prostate disease/glaucoma).

(II) Induction of anesthesia: Target-controlled infusion (TCI) of propofol 2–4.0 µg/mL and sufentanil 0.1–0.2 µg/kg is performed to induce anesthesia. LMA is placed after the BIS value drops below 60, during which no muscle relaxant is used.

(III) Maintenance of anesthesia: TCI of propofol 1.5–3.5 µg/mL and remifentanil 0.1–0.2 µg/kg is performed to maintain anesthesia. Dexmedetomidine 0.5–1 µg/kg/h is given to maintain Bispectral index (BIS) at 40–60. Dexmedetomidine is stopped immediately after the beginning of closing the pleural cavity, and propofol and remifentanil are withdrawn immediately after the beginning of skin suturing.

(IV) Ventilation: The LMA relates to the anesthesia machine to enable spontaneous breathing. The oxygen is supplied through the LMA at a rate of 2–3 L/min, and the concentration of the inhaled oxygen is adjusted between 50% and 100%. During the anesthesia period, if SpO_2 gradually decreases to below 90%, the infusion rates of anesthetics should be adjusted first, followed by synchronized intermittent mechanical ventilation (SIMV) (or other modes of assisted ventilation) or ventilation should be manually assisted to improve oxygenation; if $PaCO_2$ is ≥60 mmHg, the infusion rates of anesthetics should be adjusted first, followed by SIMV or manually assisted ventilation to improve oxygenation; if hypoxemia or hypercapnia persists despite the above treatment, a conversion to intubation is required.

(V) Intraoperative physiologic monitoring includes blood gas analysis, continuous monitoring of electrocardiogram (ECG), heart rate (HR), blood pressure (BP), pulse oxygen saturation (SpO_2), respiratory rate (RR), and pressure of end-tidal carbon dioxide ($ETCO_2$).

Surgery

Surgical steps

The patient is placed in a lateral position with the upper arms being extended and fixed on an arm supporting frame. The surgical access can be performed according to either a uniportal or multiport SV-VATS approaches. Regardless the chosen surgical approach, the incision on the chest wall at the surgical site will induce an iatrogenic pneumothorax resulting in an eventual lung collapse, which offers an optimal view of the lung ensuring a stable surgical environment. During the operation and when indicated, the linear cutter/stapler is used for wedge resection, which removes both the targeted bullae and the adjacent degenerative lung tissue. Chemical pleurodesis is not performed during the operation; however, in some centers, pleural abrasion at the apex of the pleural cavity is routinely carried out. After the surgery, irrigation of the pleural cavity by warm sterile saline solution or warm water, and re-inflation of the operated lung by manual positive pressure ventilation at a pressure of 2 kPa is carried out to test the presence of air leaks. Usually, minor air leaks do not require any additional treatment whereas major air leaks can require additional stapler application or apposition of biological glues or other sealing materials to ensure an optimal aero stasis. After that, one chest tube is placed, directed towards

the apex of the thoracic cavity. The patient is turned into a supine position after the chest is closed, and a 2-kPa negative pressure drainage device is used to evacuate the air through the chest tube to re-inflate the collapsed lung. If there is no air leak, the tube can be put under water seal (pressure of 0.8 kPa).

The patient is sent back to the recovery room following the extubation.

Operational precautions

(I)   Before the thoracic vagus nerve is blocked, the operation should be performed with extra caution. For instance, excessive pulling of the lung tissue will cause a pleural reaction and thus increase bulging of the mediastinum or diaphragm.

(II) Warm sterile saline solution or water should be used when testing for air leaks. The warm fluid should not be poured rapidly into the chest cavity, as it may stimulate the pleura or vagal and thus increase diaphragmatic bulging or even cause cardiac arrest. If necessary, the SIMV mode can be used.

(III) In some patients, the lung lobe where the bullae are removed may be poorly re-inflated during lung recruitment maneuvers, which may be due to the decreased compliance of the lobe after removal of parts of its tissue or the leakage of the LMA. Whenever required at the end of the operation, a negative pressure may be applied to the chest tube to assist the anesthesiologist's lung recruitment maneuvers and facilitate a complete lung re-expansion.

Timing of LMA withdrawal

(I)   The patient is awake and can open eyes when called.

(II) Inhalation of air via LMA: SpO_2 >95% for 5–10 min (or PaO_2 >85 mmHg, $PaCO_2$ <50 mmHg).

(III) Tidal volume (VT) >6–8 mL/kg.

(IV) Hemodynamic parameters are stable.

Intraoperative complications management

Mediastinal bulging in artificial pneumothorax

Excessive mediastinal bulging may negatively affect surgical maneuvering. This is because of one-lung spontaneous breathing and the effects of anesthetic drugs (especially propofol) on breathing after the establishment of pneumothorax. The ideal parameters of one-lung spontaneous breathing are VT 3–4 mL/kg and RR 10–15 beats/min. Since dexmedetomidine has a small effect on respiration, the dose of dexmedetomidine remains constant during the surgery. The VT and respiratory rate of spontaneous breathing can be changed by adjusting the infusion rate of propofol.

Intraoperative cough

A cough reflex is induced by stretching the hilum or by compressing the bronchial cartilage and may interfere with SV-VATS bullectomy. Visceral pleural surface anesthesia + vagus nerve block at the surgical site can effectively inhibit cough reflex.

Intraoperative hypoxemia

The incidence of hypoxemia is usually low. However, if SpO_2 is below 90%, manually assisted ventilation or synchronized intermittent mechanical ventilation (SIMV) (FiO_2 =100%, VT 3–5 mL/kg, RR 12–15 times/min, and oxygen flow 4–5 L/min) can be applied. When the operated lung completely collapses, the airway resistance of the operated side is higher than that of the contralateral side. During low VT ventilation, most ventilated gases will enter the contralateral lung, which does not cause the inflation of the operated lung and has a negligible impact on the surgical operation.

Intraoperative hypercapnia

If arterial carbon dioxide tension ($PaCO_2$) is ≥\60 mmHg, manually assisted ventilation or synchronized intermittent mechanical ventilation (SIMV) (FiO_2 =100%, VT 3–5 mL/kg, RR 12–15 times/min, and oxygen flow 4–5 L/min) can be applied, along with the adjustment of the infusion rate of propofol. If the above treatment fails to improve hypercapnia and the $PaCO_2$ is ≥80mmHg, conversion of the anesthesia method may be considered (the conversion of anesthesia method is not based on time but depends on the changes in vital signs; see the conversion conditions).

Intraoperative airway management

(I)   The positional shift of the LMA: the possibility of a positional shift of an LMA may be considered during operation if the patient suddenly experiences inspiratory dyspnea, if end-tidal carbon dioxide

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(pETCO$_2$) waveform suddenly becomes flat or disappears, and/or if VT suddenly drops. The location of the LMA needs to be properly adjusted under deeper anesthesia.

(II) Air leak test after re-inflation of the operated lung: Re-inflation of the operated lung may be difficult if there are air leaks from the LMA. Air leakage may be reduced by gently pressing the two sides of the thyroid cartilage, or by repositioning the Laryngeal mask, with an occasional need for a bronchoscopic assessment to ensure an adequate position.

(III) Intraoperative sputum suctioning: If sputum suctioning is required through the LMA, the negative pressure should be <10kPa, and each suction should last for <10 s. Repeated stimulation of the glottis should be avoided as it may cause cough and laryngospasm. Local anesthetics can be obtained by application of lidocaine spray over the upper airways.

Intraoperative conversion to intubated anesthesia

Intraoperative conversion from non-intubated anesthesia to intubated anesthesia is a major challenge for anesthesiologists during SV-VATS. For this reason, the anesthesiology team must master this skill before being involved in such operations.

(I) Conversion conditions:

(i) Hypoxemia: SpO$_2$ <85%, which is not improved after SIMV;

(ii) PaCO$_2$ ≥80 mmHg, which is not improved after SIMV, along with the presence of any of the following criteria:

❖ Change in circulation: HR >100 bpm, or systolic pressure changes by >30% of the baseline value;

❖ Arrhythmia: frequent atrial or ventricular premature beats ≥6 times/min (not caused by surgical stimulation);

❖ pH value <7.15 at 2 sessions of arterial blood gas test (performed at intervals of 15 minutes or more).

(iii) Excessive lung movement lasting more than 5 minutes despite optimized pharmacological treatment makes it difficult to operate.

(iv) Severe bleeding in the surgical wound and thoracic cavity blurs the surgical field.

(v) The tracheal secretions (especially the bloody secretions) remarkably increase, leading to difficulty breathing and increased airway resistance. VT decreased by >30% during spontaneous breathing with the peak flow being >20 cmH$_2$O during mechanical ventilation.

(vi) After opening the pleural cavity for surface anesthesia and vagus nerve block, the cough persists at a high rate (e.g., >2 times/min).

(II) Selection of an endotracheal tube during conversion to intubated anesthesia

(i) Single-lumen endotracheal tube + bronchial blocker device (preferred);

(ii) Double-lumen bronchial tube (if lung isolation due to excessive bleeding or secretion in the airway, double-lumen endotracheal intubation is recommended).

(III) Tracheal intubation at the lateral position

(i) The head is supported with a small square pillow to make the anterior and inferior sides of the mouth and nose free to access;

(ii) The head and neck are parallel to the central axis of the body;

(iii) A visual laryngoscope is used;

(iv) Catheter shaping is applied; and

(v) Two staff members cooperate closely.

Postoperative management

Routine postoperative monitoring

The following indicators are evaluated after surgery:

(I) A second chest X-ray examination and routine blood tests are performed within 24 hours after surgery.

(II) Postoperative feeding: fluid supplementation may be initiated 4–6 hours after surgery, and water intake can be gradually increased. If water intake is well-tolerated, and there is no nausea or vomiting, a regular diet can be resumed.

(III) Postoperative ambulation: patients should be encouraged to become ambulatory as soon as possible after surgery to reduce risks of complications such as atelectasis and venous thromboembolism.

Use of antibiotics

Typically, only one dose of antibiotic is given before surgery, and no antibiotic is given after surgery. If the frequency of antibacterial use is bid, 1 dose can be used on the day after surgery. Postoperative antibacterial drugs are used only if

one of the following criteria is met or when the treating physician believes it is necessary to use antibiotics:

(I) If the operation lasts more than 4 hours or has massive blood loss (>1,500 mL), a second dose of the antimicrobial drug should be applied during the surgery;

(II) A body temperature higher than 38.5 ℃;

(III) With substantial amounts of purulent sputum or positive sputum cultures;

(IV) With elevated procalcitonin level that does not remarkably decrease to 2 nm/mL or lower within 48 hours;

(V) With elevated white blood cell (WBC) count that increases to 10×10^9/L or higher after surgery and does not fall to the normal range within 48 hours; and with radiologic evidence of pleural effusion on chest X-ray.

Evaluation of postoperative lung re-inflation

(I) Evaluation method: chest X-ray scans are performed within 24 hours after surgery, after removal of the chest tube, and 1–2 weeks after discharge

(II) Evaluation criteria: lung re-inflation is evaluated as good (lung re-inflation ≥70%), medium (70% > lung re-inflation ≥50%), and poor (lung re-inflation <50%) according to the degree of postoperative lung recruitment.

Management of chest tubes

(I) Criteria for tube removal: the chest tube can be removed as soon as chest X-ray or chest CT reveals good lung re-inflation, and there is no obvious air leak, active bleeding, or substantial amounts (>200 mL/24 h) of exudate.

(II) Re-placement of chest tube: the drainage tube may be replaced in the chest cavity if the lung re-expansion is still inadequate at follow-up chest X-ray, or if there is a residual abundant pleural effusion. In these instances, thoracentesis may be first required due to poor lung re-inflation and the presence of intrathoracic effusion before deciding to re-insert a chest tube.

Pain scoring based on international pain scoring criteria and use of analgesics

Pain assessment is performed within 24 hours after surgery.

The scoring criteria are as follows:

Visual Analogue Scale (VAS, 0–10 points):

(I) 0 points, no pain;

(II) ≤3 points, slight pain that is endurable;

(III) 4–6 points, pain affecting sleep that may still be endured;

(IV) 7–10 points, increasingly strong pain that cannot be endured, affecting appetite and sleep.

Morphine 5 mg can be intramuscularly injected if the pain score is higher than 4 (morphine should be used with caution in minors, and intramuscular injection of tramadol or ketorolac is preferred in patients older than 12 years).

Postoperative complications and their management

Atelectasis

Atelectasis might be caused by mucus or blood accumulation in the airways causing bronchial obstruction occurring during surgery or in the early postoperative period. Intensified expectoration of sputum with mechanical means is recommended. Bronchoscope sputum suctioning can be considered in selected instances if necessary.

Poor lung re-inflation

Poor lung re-inflation may be due to air leaks or inadequate postoperative suctioning with negative pressure. Constant low negative-pressure suction (<2 kpa) in the thoracic cavity or biphasic intermittent positive airway pressure (BiPAP)-assisted ventilation (2 h/bid) may promote lung re-inflation. Chest tube patency should always be assessed to prevent a blocked tube with resultant inadequate suction activity.

Other complications of SV-VATS

Other complications can occur, and their management does not differ from that applied to any other perioperative complications after standard thoracic surgery.

Conclusions

Intravenous anesthesia with spontaneous breathing has been applied in VATS, as it is deemed to offer fewer side effects than anesthesia with endotracheal intubation, thus potentially enabling faster postoperative recovery. Many studies have demonstrated that SV-VATS bullectomy is safe and feasible for the treatment of PSP (9,13,31).

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PSP patients are often young and have good pulmonary function, stable hemodynamics, and only few comorbidities if at all, making the effects of intravenous anesthesia more predictable and stable intraoperative physiologic management is more easily maintained. These patients uncommonly develop severe hypoxemia and can tolerate satisfactorily permissive hypercapnia. SV-VATS bullectomy typically does not involve the hilum and main bronchi, thus avoiding coughing induced by intraoperative lung traction. Additionally, the duration of the operation is short, and intraoperative complications such as bleeding are extremely rare. For all these reasons, SV-VATS bullectomy can be considered a simple and efficient alternative to the standard VATS bullectomy method performed by double-lumen tube intubation and single-lung mechanical ventilation anesthesia.

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Footnotes

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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