Review Article on Thoracic Surgery

Anaesthesiology for uniportal VATS: double lumen, single lumen and tubeless

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Abstract: The advent of one-lung ventilation (OLV) technique provides immobilized surgical field which is fundamental in minimally invasive thoracic surgery. Mainstem methods of achieving lung separation are either via a double-lumen endotracheal tube or placing a bronchial blocker (BB) through a single-lumen endotracheal tube. More recently, the use of non-intubated thoracic surgery (NITS) has been investigated intensively, attempting to minimise the complications that follow general anaesthesia. The aim of this review is to describe the mechanism of these techniques briefly and outlines the advantages and drawbacks of them with the comparison.

Keywords: Double-lumen endotracheal tube; endobronchial blocker; one-lung ventilation (OLV); non-intubated thoracic surgery (NITS); video-assisted thoracoscopic surgery (VATS)

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Introduction

Since the advent of video-assisted thoracoscopic surgery (VATS), endobronchial intubation has become fundamental to thoracic anaesthesia as it facilitates stabilize surgical field in the pleural cavity. Lung isolation was primarily used to produce an immobile surgical field, and control or aspirate secretions and pus. The goal is to protect the non-diseased contralateral lung from contamination via one-lung ventilation (OLV). Lung separation, on the other hand, refers to situations that mainly to improve surgical exposure as for the modern minimally invasive thoracic practices. With the wide-spreading concept of personalised medicine (1), there has been a resurgence of interest in awake, non-intubated transpleural surgery (2,3). The purpose of this review is to provide a brief introduction of endobronchial intubation and tubeless techniques for uniportal VATS practices.

Physiology alternation following OLV

The major physiologic change associated with OLV is the redistribution of lung perfusion between the ventilated and non-ventilated lung. The increased shunt flow to the nondependent (non-ventilated) lung due to lung collapse may result into a decreased PaO_2. Hypoxic pulmonary vasoconstriction (HPV) is a physiologic adaption that allows redistribution of blood flow to alveoli with higher oxygen which happens in the dependent lung during decubitus position. Thus, the ventilation/perfusion mismatch would decrease. The application of continuous positive airway pressure (CPAP) that used during thoracotomy may cause the obstruction of surgical field in uniportal VATS. An alternative method of improving oxygenation during OLV for VATS includes positive end-expiratory pressure (PEEP) to the dependent lung or intermittent bronchoscopy-guided insufflation into segments of the nondependent lung remote to the site of surgery.

Single lumen endobronchial tube (SLT) and bronchial blocker (BB)

SLT with two cuffs was described by Rovenstine *et al.* (4) for the establishment of OLV. Bilateral lungs can be ventilated when the upper cuff was inflated; OLV was achieved by deflating the upper cuff while inflating the lower cuff, leading the non-intubated lung to be collapsed. The main drawback of SLT is that secretions cannot be aspirated from the nondependent lung. Especially, the orifice of the right upper lobe can be obstructed as it originates at 1.5–2 cm from the carina. Hence, SLT is no longer served as a usual method of obtaining OLV and was then gradually replaced by BB or double lumen tube in elective VATS procedures.

The BB involves blockade of a main-stem bronchus to allow lung collapse distal to the occlusion. More distal bronchi can also be blocked, allowing for selective isolation than DLTs. Either a standard endotracheal tube or a modified SLT like the Univent tube (Fuji Systems Corporation, Tokyo, Japan) with a separate channel can be applied for introducing a BB. Once the catheter is in position by the confirmation of flexible fiberoptic bronchoscopy (FOB), the balloon of BB is inflated to obstruct the airway. It is also worth noted that increased airway pressures and difficulty with ventilation would occur when placing a BB by FOB guidance through a small-lumen SLT. Therefore, a larger size SLT is hence favoured though anaesthesiologists should be aware of the associated increased risk of trauma to the airway. This pressure is to some extent reduced by the newest BB have high-volume, low-pressure characteristics. The previous report suggested that the optimal positioning of the balloon would be at least 10 mm distal to the carina inside the bronchus to be blocked (5).

Double lumen endobronchial tube (DLT)

Each DLT is composed of two bifurcated tubes of unequal length. The shorter tube terminates in the trachea, while the longer one reaches into a bronchus. A cuff placed above the distal opening of the endobronchial lumen prevents gas leaks during positive pressure ventilation. Intermittent suction via the DLT would help expedite lung collapse.

Considering the anatomical characteristic of the right upper lobe bronchus mentioned above, a left-sided DLT is favoured for elective procedures. There are still circumstances as operations involving the left main-stem bronchus or distorted left main-stem bronchus that a right-sided DLT is still indicated. For these reasons, a modern right-sided DLT incorporates a modified cuff with a slot on the endobronchial side which allows ventilation through the upper lobe orifice (6). Thus, the FOB should be applied to confirm that the fenestration overlies the opening of the right upper lobe bronchus to help prevent hypoxia. Though blind insertion after direct laryngoscopy is commonly used, placing DLT under direct vision by FOB can reduce the risk of trauma and hypoxemia from malposition.

Comparison of DLT and BB

In general, the pros and cons of each technique can be outlined as follows:

(I) Advantages for DLT
- ❖ Easier placement and quicker isolation (7,8);
- ❖ Quicker deflation of the nondependent lung (5);
- ❖ Bilateral lung inspection with FOB (9);
- ❖ Able to deflate and re-inflate the lung any time during operation (7);
- ❖ CPAP can be applied during OLV;
- ❖ Less cost.

(II) Disadvantages for DLT
- ❖ Increased risk of airway trauma (10);
- ❖ Raised incidence of hoarseness and sore throat (10);
- ❖ Difficult or unable to place in abnormal airway anatomy;
- ❖ Require exchange DLT for an SLT if postoperative ventilation is required to prevent mucosa necrosis (5).

(III) Advantages for BB
- ❖ Can be used in paediatrics and challenging airway intubation;
- ❖ Allows for selective lobar blockade;
- ❖ No requirement to change to the endotracheal tube if postoperative ventilation is required.

(IV) Disadvantages for BB
- ❖ Greater chance of malpositioning (9);
- ❖ More time consumed for correct placement (9);
- ❖ Modest augment in dead space and peak pressure (19 cmH_2O compared with 16 cmH_2O of DLT) (10);
- ❖ May not allow conversion to thoracotomy (5);
- ❖ CPAP cannot be applied (high-frequency jet ventilation can be a substitute);
- ❖ More expensive.

(V) Current evidence

Though DLT is the more preferred choice for lung isolation (11), numerous randomised trials failed to give a significant difference between these two approaches. A systemic review and meta-analysis conducted by Clayton-Smith *et al.* (9) that recruited comparative studies of DLT and BB between 1996 and 2014 showed that DLTs could be placed 51 seconds [95% confidence interval (CI): 8–94 seconds] faster than BBs. Moreover, DLTs were more likely to be placed correctly [odds ratio (OR) 2.7; 95% CI: 1.18–6.18] but were more expensive. No difference was spotted regarding the time taken for lung collapse. However, BBs had certain advantages of lesser incidence of postoperative sore throat (OR 0.39; 95% CI: 0.23–0.68), hoarseness (OR 0.43; 95% CI: 0.21–0.75), and fewer airway traumas (OR 0.40; 95% CI: 0.21–0.75) than DLTs. Though these cumulative evidence demonstrated efficacy in each approach, some may argue that these differences be relatively irrelevant in clinical practice. Thus, for most thoracic procedures, either a DLT or BB can be used and is up to the anaesthesiologist's practice, skill and institutional preference.

Non-intubated VATS

In view of the associated injuries with endobronchial tubes, tube dislocation during position alternation, mechanical ventilation, and general anaesthetic drugs with certain complications and side effects, there has been a resurgence of investigating non-intubated thoracic surgery (NITS) in the past decade. Accumulating reports suggest that NITS can be applied to the majority of VATS procedures including anatomical resection, though the optimal criteria for patient selection and standard anaesthetic care remain to be clarified.

Physiology of NITS

Following iatrogenic pneumothorax, collapsed lung occurs due to the loss of negative pressure in the pleural cavity. Compared with general anaesthesia, the anaesthetic agents used for NITS like propofol via thoracic epidural anaesthesia (TEA) have a lesser inhibitory effect on the vasomotor response than volatile anaesthetics. More importantly, NITS leads to lesser interference with the functional residual capacity of the dependent lung because of the preserved function of the diaphragm. However, the spontaneously breathing dependent lung would exhale air into the nondependent lung and inhales part of the air volume that just filled the operated lung, which is known as paradoxical respiration. This process would result in hypercapnia that may stimulate tachypnoea, though a transient hypercapnia (<55 mmHg) can generally be tolerated (permissive hypercapnia) (12).

The spirometric changes induced by surgical pneumothorax in awake patients in the lateral decubitus position demonstrated that lesser ventilatory impairment (decline of FEV1 and FVC, and fewer drop in PaO_2 relative to the fraction of the inspired oxygen ratio) in the already diseased malfunctioning lungs compared with relatively normal lung (13). These findings support the appealing idea of using NITS in patients with compromised lung function.

Advantages over intubated approaches

A main advantage of NITS stems from avoiding perioperative complications associated with general anaesthesia and OLV. Despite numerous strategies described (14,15), general anaesthesia is associated with higher risks of pneumonia, impaired cardiac function, and a residual neuromuscular block in patients with myasthenia gravis (16,17). Awake anaesthesia without endotracheal intubation can avoid complications such as hypoxia due to the displacement of the DLT, hyperinflation of the dependent lung, re-expansion pulmonary oedema, ventilator-induced lung injury, and atelectasis in the dependent lung. Additionally, the technique could be useful in handling complications following pneumonectomy (18).

Contraindications of NITS

Expert opinions from experienced centres of NITS suggested exclusion criteria be classified as patient-, anaesthesiologist-, and surgeon-related factors (19-21) (*Table 1*).

Anaesthetic setting in NITS

Locoregional anaesthesia and sedation, such as local wound infiltration or selective intercostal nerve blockade would be sufficient for intra- and postoperative pain control of minor thoracoscopic procedures, and can even achieve satisfying anaesthesia in obese patients (22,23). However, major procedures warrant sophisticated anaesthesia techniques. TEA blocking T2–T10 can induce long-lasting bilateral anaesthetic effects on the chest wall and pleural cavities, although the bronchial tone and airway hyper-reactivity may increase (24). In contrast, a paravertebral blockade through a T4–T5 level that blocks the sympathetic system unilaterally can offer pain relief like TEA but with fewer

Table 1 Contraindications to non-intubated thoracic surgery

Patient-related factors
Allergy to local anaesthetic; coagulopathy (international normalized ratio >1.5 or current antiplatelet therapy); haemodynamically unstable; elevated risk of regurgitation (<6 hours fasting); hypoxaemia (PaO_2 <60 mmHg) or hypercapnia ($PaCO_2$ >50 mmHg[†]) preoperatively; neurological disorders; obesity (body mass index >30[‡]); persistent cough or high airway secretion; spinal deformity or brain edema (if thoracic epidural anaesthesia to be used)
Anaesthesiologist-related factors
Any contraindications for the use of regional anaesthesia technique specifically selected; difficult airway management
Surgeon-related factors
Extensive pleural adhesions; Inexperienced and poorly cooperative surgical team; Previous ipsilateral thoracic surgery

[†], >55 mmHg in Pompeo's criteria (21); [‡], >35 in Mineo's report (19).

side effects (25). Manipulations of the hilum structures during major lung resection under NITS may provoke uncontrollable coughing, which is a substantial safety hazard, particularly during delicate vascular dissection. Though not always necessary, useful preventive measures include the administration of lidocaine by either inhaling aerosols or spraying it on the pleural surface, and intrathoracic stellate ganglion or vagus blockade, which can provide inhibition for around 3 hours or more (26).

The need for sedation with uniportal VATS in the non-intubated patient remains unclear (20). However, sedation is preferred for prolonged operations, with the use of short-acting agents like remifentanil at below the hypnotic level being the first choice (26). One of the benefits of administering sedation is that remifentanil may blunt the cough reflex during the anatomical dissection. However, such agents can also be respiratory suppressants (27) and accentuate hypercapnia, especially when treating patients with the severe chronic obstructive pulmonary disease. In such cases, monitored anaesthesia care is essential during NITS and includes monitoring of the respiratory rate, exhaled partial pressure of CO_2 (e.g., end-tidal capnography), and the bispectral index.

Conversion to intubation during operation

The overall conversion rate of NITS to general anaesthesia ranged from <1% to 9% based on reports involving more than 1,400 patients from 15 centres (19). Situations warranting conversion included surgery-related events such as excessive adhesions (0.69%), bleeding (0.34%), and anaesthetic problems such as mediastinal movement (0.34%), hypoxaemia (0.27%), intractable cough (<0.10%), or hypercapnia (<0.10%), with major procedures at greater risk. The decision to convert should be made jointly by the surgeon and anaesthesiologist. Though intubation of a patient in the lateral decubitus position under FOB guidance is challenging, it could be successfully performed by experienced anaesthesiologists (28). During conversion, an insertion of a chest drain through the surgical incision with covering by transparent waterproof dressing would allow re-expansion of the operated lung for optimal oxygenation and lessen the mediastinal shift.

Current evidence of NITS for thoracic procedure

Modern application of NITS for thoracic practice is entirely different from the era before the advent of OLV as its safety and feasibility have been gradually proved. Shorter hospital stays and reduced procedure-related costs have been shown in treating spontaneous pneumothorax by bullectomy with pleural abrasion compared with general anaesthesia through a small randomised trial (29). The NITS technique for non-resection lung volume reduction surgery for emphysemas had also shown similar postoperative survival when compared with intubated surgery. However, NITS group had advantages with less mortality, morbidity, and shorter hospital stays (30). Similarly, awake endoscopic thymectomy via an infrasternal approach has been reported and allows the patient to eat, drink, and walk several hours postoperatively (31) without the risk associated with muscle relaxants in myasthenia gravis.

In 2004, Pompeo *et al.* reported randomizing 60 cases with solitary pulmonary nodules to general anaesthesia and awake VATS wedge resection groups. The conversion rates and technical feasibility were comparable between the groups. Anaesthetic satisfaction, the changes in arterial oxygenation, and the need for nursing care were more favourable in the awake group. Importantly, the hospital stay was shorter in the awake surgery patient group (47% *vs.* 17% of the patients were discharged within 2 days) (32). The application then extended by Tsai *et al.* (33) for bilateral wedge resection of peripheral nodules can be performed under NITS, avoiding sequential OLV which may reduce the risk of haemodynamic disturbance. A further attempt to the goal of outpatient management was reported by Rocco *et al.* (34), as they conducted the first awake uniportal VATS wedge resection. By using the Fogarty balloon under FOB guidance to selectively occlude the target parenchyma during NITS, surgery was successfully completed and the chest tube was removed on postoperative day one with the whole procedure done in an ambulatory setting.

After successfully applying NITS for relatively minor procedures mentioned above, surgeons from experienced institutions tried to broaden its indication to major lung resection, which is more technically demanding with frequent hilar manipulation, a greater chance of bleeding, and longer operation durations. Major thoracic procedures with TEA and stellate ganglion blockade were first described by Al-Abdullatief *et al.* (35) in 2007. They analysed a cohort of 79 patients, including 11 anatomic lung resections, with an overall conversion rate of 11%, and only 5 patients went to the intensive care unit postoperatively. Consequently, several investigators have proposed using non-intubated techniques in VATS anatomic pulmonary resection in the hope of improving the postoperative experience and reducing hospital stay and complications when compared with general anaesthesia (36,37). While many studies favour TEA, the intrathoracic intercostal block can also provide satisfactory intra- and postoperative analgesic outcomes (38).

More recently, Gonzalez-Rivas *et al.* reported the first non-intubated single-port VATS right middle lobectomy. Local intercostal infiltration was used without the vagal blockade, and the patient was discharged 36 hours postoperatively (24). The same group also subsequently reported their preliminary experience of uniportal non-intubated major pulmonary resection with promising results. In their series, only 2 of the 30 patients (6.6%) required intubation (one due to bleeding and the other because of excessive diaphragm movement) and the operation could still be completed with single-port VATS (20). Such non-intubated single port VATS techniques are becoming more popular and increasingly being accepted as part of the armamentarium of the advanced minimally invasive thoracic surgeon (39).

Summary

For most VATS procedures, lung separation can be achieved effectively through BB and DLT with the aid of FOB. Compared with BB, DLT is cheaper, quicker to be position reliably but cause more airway complications. With the growing evidence demonstrating the feasibility of NITS for minor procedures such as talc pleurodesis, mediastinal biopsies, and managing pericardial effusions, the application of NITS for major lung resection continues to be elucidated. Further RCTs that focus on important clinical outcomes measuring efficacy and patient safety are required to improve the evidence base to allow for comparison of the current different anaesthetic techniques in the future.

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Footnote

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