Review Article

Anesthesiology of the spontaneous ventilation in thoracic surgery: a narrative review

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Objective: Thanks to the growing experience and the improvement of video-assisted thoracoscopic surgery (VATS) technique most pulmonary resections can now be performed by minimally invasive techniques. The present and the future of the thoracic surgery should be associated with a combination of surgical and anaesthetic advancement and improvements to reduce the perioperative surgical stress on the patient.

Background: Traditionally intubated, ventilated general anaesthesia with one-lung ventilation was considered necessary for thoracoscopic major pulmonary resections for all patients. An adequate analgesia technique (regional or epidural) allows VATS to be performed in anesthetized patients and the potential adverse effects related to general anaesthesia and mechanical one-lung ventilation (mOLV) can be avoided.

Methods: A search was carried out on the databases PubMed, Web of Science and The Cochrane Library by means of the medical subject headings (MeSH)terms 'non intubated thoracic surgery', 'spontaneous breathing', 'regional blockade', 'cough reflex', 'mechanical ventilation' and 'pulmonary complications' screened according to the following inclusion criteria: availability as full text in English, categorization as original research, reviews or meta-analyses.

Conclusions: The minimally invasive, non-intubated procedures try to minimize the adverse effects of general anesthesia, tracheal intubation, and mechanical ventilation. Furthermore, patients may have also benefited from preserved hypoxic pulmonary vasoconstriction from the efficient contraction of the dependent hemidiaphragm during surgically induced pneumothorax. The non-intubated anaesthesia combined with the uniportal surgical approach represents one step forward in the minimally invasive strategies of treatment and can be a reliable offer to an increasing number of patients. Therefore, educating and training programs in minimally invasive techniques for spontaneous breathing (SB) patients may be needed and the continuous evolution and findings of the better and better anesthetical and surgical methods are vital in reduction of the perioperative complications.

Keywords: Video-assisted thoracoscopic surgery (VATS); spontaneous breathing (SB); intubation; double-lumen tube; paravertebral blockade

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Introduction

Mechanical ventilation is necessary during many surgical procedures, however a paradigm shift in ventilation has taken place in the past few decades. The neuromuscular blockade and subsequent controlled mechanical ventilation applying intermittent positive pressure, also in patients with non-injured, healthy lungs, may impair the respiratory system, leading to postoperative pulmonary complications (PPCs) with worse clinical outcome, prolonged hospitalization time and increased costs of hospital care. The incidence of PPCs is 4.8–54.6% after thoracic surgery (1,2).

POPULAR study indicated that the use of neuromuscular blocking agents (NMBAs) during general anesthesia is associated with an increased risk of PPCs (3). The publishers of this study recommended that anesthetists must balance between the potential benefits of neuromuscular blockade and usage of supraglottic airway devices and maintaining spontaneous breathing (SB) during minor surgical procedures. There is a continuously growing experience based on evidence about the advantageous effects of spontaneous ventilation on respiration of non-intubated anesthesia in thoracoscopic and open thoracic surgery (4-10). We present the following article in accordance with the Narrative Review reporting checklist (available at https://asj.amegroups.com/article/view/10.21037/asj-21-22/rc).

Physiological and pathophysiological changes during thoracic anaesthesia

In awake patients the lateral decubitus position does not influence the ventilation—perfusion matching, explained by the more effective contraction of the dependent hemidiaphragm and by that the dependent lung is on a more favorable part of the compliance curve attended with greater perfusion in the dependent (lower) lung due to gravitational influence.

Under general anesthesia before the chest opening, ventilation—perfusion mismatching can evolve because induction of anesthesia, by decreasing functional residual capacity (FRC), moves the dependent lung to a less favorable part of the compliance curve, opposite is happening with the nondependent lung, so ventilation becomes greater in the nondependent lung, whilst the perfusion remains unchanged. By opening the chest on one side, spontaneous ventilation with open pneumothorax has two clear pathophysiological consequence, mediastinal shifting, and paradoxical respiration (pendelluft). The advantages of SB are summarized in *Table 1*.

The undergone developments in minimally invasive techniques gave us the chance to maintain spontaneous ventilation in the setting of non-intubated thoracoscopic surgeries (NITS) and intubated stroke volume index (SVI) method. In the reflection of the results of last few years it seems, that the advantages of maintained SB overcome on potential risks (11,12).

Transpulmonary shunt

During mechanical one-lung ventilation (mOLV) only the dependent lung is ventilated, while the perfusion of the non-ventilated lung is maintained, lead to transpulmonary right to left shunting. Shunt fraction is the proportion of the total cardiac output (pulmonary blood flow) that does not take part in gas exchange. Under physiological circumstances transpulmonary shunting also exist, normally it is between 6–10%, caused by the drainage of Thebesian and bronchial veins and other right-left shunt pathways (13).

Rise of transpulmonary shunt fraction decreasing the arterial oxygen content, as higher fraction of the total cardiac output shunted from right to left without oxygenation, and what seems to be more important the elevation of FiO_2 has less effect on oxygenation as shunt fraction increases as it is seen on Nunn's adapted iso-shunt diagram (14).

With increasing shunt fraction, the higher FiO_2 is unable to elevate the alveolar oxygen content in unventilated segments, and the extra oxygen content given to blood by ventilated segments is not enough to compensate the effect of high shunt.

During mOLV the transpulmonary shunt fraction can be as high as 20–30%, and if this ventilation—perfusion mismatch kept uncompensated by the patient, it could lead to severe hypoxemia. The compensation mechanism is the hypoxic pulmonary vasoconstriction (HPV), which means the constriction of intrapulmonary arteries in response to low alveolar oxygen tension. This phenomenon was first mentioned by Bradford and Dean (15), while the first detailed description of the mechanism of HPV is published by von Euler and Liljestrand (16). The exact molecular mechanism of HPV is out of this article's range. Simplified, resting membrane potential (approx. –60 mV) in pulmonary artery smooth muscle cells maintained by outward potassium current. In hypoxic environment this potassium current is inhibited and by depolarization of the membrane the opening calcium channels will cause a rise in cytoplasmic Ca^{2+} level, resulting the contraction of

Table 1 Advantages of spontaneous breathing

Intact respiratory muscle tone
Restored diaphragmatic function
Improvement of dorsal ventilation
Prevent ventral redistribution of ventilation
Improved V/Q matching
Improved gas exchange
Maintenance of distal airway patency
Prevent atelectasis
Preserved or increased FRC
Preserved function of mucocilliary clearance
Avoiding the use of NMBAs

V/Q, ventilation/perfusion ratio; FRC, functional residual capacity; NMBAs, neuromuscular blocking agents.

pulmonary arteries (17-19).

HPV is a fast-acting mechanism, has its maximum effect in minutes (3,20). Until vascular remodeling, HPV is reversible, it can be global or local which is the case in thoracic anesthesia. On HPV blood flow directed from the non ventilated areas to open lung fields, thus optimizing the perfusion—ventilation matching and systemic oxygen delivery.

Adequate HPV is crucial for minimizing the perfusion of nondependent lung, and by that decreasing shunt.

Possible physiological changes during non intubated thoracoscopic surgery

Due to the development of thoracic anesthesia and minimally invasive surgical techniques the opportunity of maintenance of SB during thoracic surgeries are given. In the setting of NITS and SVI several possible physiological changes should be considered to understand the differences and the possible advantages of this methods.

Position of the patient mostly depends on the surgical procedure and not by the applied anesthetic technique, so greatest part of the surgeries performed in lateral decubitus position, as it happens in ventilated cases, with all of its advantages and disadvantages.

During m*OLV* the rapidly evolving hypoxic pulmonary vasoconstriction is responsible for an acceptable *V/Q ratio* during the surgery, however, it is influenced by several factors like the lung volume. Positive pressure ventilation, by generating high positive airway pressures [PEEP, auto-PEEP, peak inspiratory pressure (PIP)] can demolish the effect of HPV by indirectly increasing the perfusion of the nondependent lung. By maintaining SB the physiological excursion of diaphragm improves lung recruitment, prevent atelectasis and redistribution of ventilation, and by avoiding high positive airway pressures in the dependent lung, perfusion is not diverted to nondependent areas. These advantageous mechanisms might improve V/Q matching, theoretically results in lower intrapulmonary shunt fraction, thus decreasing the incidence of possible complications and may be responsible for faster recovery and better patient outcome (21-25).

Methods

A search was carried out on the databases PubMed, Web of Science and The Cochrane Library by means of the medical subject headings (MeSH) terms 'non intubated thoracic surgery', 'spontaneous breathing', 'regional blockade', 'cough reflex', 'mechanical ventilation' and 'pulmonary complications'.

Discussion

Anaesthesia techniques in non intubated surgery

The evolution of thoracoscopic procedures gives non-intubated thoracic surgery a boost performed under regional anaesthetic techniques in spontaneously breathing patients.

Standard monitoring applied on regular basis (included electrocardiogram, invasive blood pressure, pulse oximetry and respiratory rate with measurement of end-tidal carbon dioxide level) and additionally depth of awareness monitoring is necessary to adjust the adequate anaesthetic level to the surgical manipulation. The pharmacological management is based on a target-controlled infusion of propofol, with a premedication of midazolam (0.05–0.2 mg/kg) and atropine (0.01 mg/kg) given by intravenously with 15 min before anaesthesia. The use of a nebulization of 5 mL of lidocaine 2% 30 min before helps to avoid coughing during surgical and anesthesiolgical manipulation (26).

It is important to mention NITS may be performed by many centres fully awake, under minimal sedation or under deep sedation or general anaesthesia. The majority of early reports of non-intubated techniques were in patients who were awake under thoracic epidural blockade for minor video-assisted thoracoscopic surgery (VATS)

procedures (4-6). These patients, however, all received pre medication with midazolam, either orally, intramuscularly or intravenously prior to epidural placement. Oxygen is delivered via nasal cannula or facemask. Awake and minimal sedation techniques also avoid potential side effects off general anaesthesia, thus maintaining a more physiological cardiopulmonary and neurological status avoiding loss of airway protecting mechanism, post-operative nausea and vomiting.

Depth of awareness monitoring is very important part of routine monitoring care in non intubated thoracic surgery to ensure adequate level of sedation for different types of thoracic operations fitted to manipulated area (27). Anaesthesia was mostly induced and maintained with propofol, administered via the target controlled infusion titrated to keep the sedation level in range of general anaesthesia level. This extra, unical information allows accurate management of sedation to inhibit the overdosage of the sedative drugs and the stoppage of the adequate SB.

There are many opportunities to administer oxygen during SB in the operation room. Popular choice is face mask with reservoir bag or high flow nasal cannula to ensure high FiO_2 but many teams are concern due to unsafe airway and the long time that is needed for the conversion. This time depends on the experience of the team. Other technique is using laryngeal mask which ensures some beneficial effect. The sedation level is in range of surgical anaesthesia therefore the insertion of supraglottic devices (SAD) is not complicated, the access to the airway is easily obtainable and very useful if conversion and intubation are needed.

Thoracic epidural anaesthesia (TEA) is used in many centers as a gold standard technique due to excellent analgesic effects but there are many disadvantages (hypotension, sympathetic blockade, technical difficulties during insertion) adjudication of TEA is made controversial by these factors.

The regional anaesthetic techniques comprehend local anaesthesia, intercostal nerve blocks, regional blocks or TEA (28,29). Other hands, these methods are insufficient to control the pleural surface and hilar and bronchial areas and the cough reflex therefore additional special nerve blockade and sedation are required (12,19,30).

According to published results with uniportal VATS suggest that excellent pain management is owed with greater extension of the regional block accomplished by paravertebral blocking. Using this technique with a single administration of local anaesthetic level T3–T6 and complete sensorial block is achieved to avoid any painful reaction during the surgical incision.

None of these techniques are able to implement the performance of thoracic surgery without sedation. Anaesthetic method includes the administration of anesthetics and opioids for sedation and using of SAD to improve ventilation, oxygenation and prevent obstruction of the airway (31). Many centres do not use SAD devices, face mask with reservoir bag or high flow nasal cannula are used to ensure adequate oxygenation. The key step during VATS resections is the control of the cough reflex with unilateral vagus nerve infiltration which is easily performed during VATS procedures under direct vision and comes with minimal secondary effects (32).

SADs are well tolerated and useful during sedation to prevent remaining of positive pressure in the airway during the expiration and to avoid the insufflation of the collapsed lung. Laryngeal mask can guarantee a permeable and easily accessible airway. Moreover, in case of hypoxemia or hypercapnia due to hypoventilation, applying of positive pressure of 5–8 mmHg might be sufficient to decrease atelectasis during spontaneous ventilation in the dependent lung. Applying of positive pressure can be performed also in non-intubated patient without the re-insufflation of the lung It allows bronchoscopy-guided endobronchial blockade in the nondependent lung while administering positive pressure with mOLV or without intubation (33).

Perioperative concerns of non intubated thoracoscopic surgery

The non-intubated thoracic surgery requires strict and accurate protocol for patient's selection including description of indications-contraindications criteria's, signed patient's consent form and protocol for the most appropriate anaesthetic technique and the criteria's for the conversion to general anaesthesia.

Hypercapnia is commonly seen factor in non-intubated thoracic surgery related to hypoventilation. The 'permissive hypercapnia' is frequently used in ventilatory strategies for patients under mOLV but the level of CO_2 can be higher due to CO_2 rebreathing phenomenon during non-intubated techniques comparing ventilated one's. It has been published the permissive hypercapnia may improve hemodynamics and the ventilation/perfusion match and protective effects in inflammatory response (34).

Hypercapnia should be avoided in patients with major cardiac rhythm disturbances or increased intracranial

pressure or elevated pulmonary pressures. Patients with normal right ventricular function tolerate well the $PaCO_2$ levels up to 70 mmHg or pH >7.2 (35).

Conversion to intubated surgery

The conversion to intubated surgery might be challenging situation in the operation rooms, therefore to ensure maximal patient safety, a clearly defined protocol for urgent intubation must be framed.

Intubation in the lateral decubitus position is a technically challenging situation for the anesthesiologist, who must be skilled in placing a double-lumen tube in this unusual setting. Depending on the patient's airway, position, time for completion of the procedure and the causes that have led to the conversion to general anaesthesia, laryngeal mask, single or double lumen tube, or endobronchial blocker can be used in order to securely finish the conversion to general anesthesia.

It is published that the surgical conversion to thoracotomy can be performed safely at the site of the utility incision without intubation using regional blockades and the major lung resections is also performed through this approach (36).

New approach in thoracic surgery: spontaneous ventilation combined with double lumen tube intubation (VATS-SVI)

Many specialists are discouraged by complications of non intubated surgery included possibility of airway problems. New method is published called VATS-SVI combining the safety of intubated techniques and advantages of SB during thoracic surgery. The mechanical one lung ventilated time is reduced with 76.6% and the immunological response is attenuated comparing with intubated VATS (37).

Conclusions

According to the published articles and based on our experience that have already had, NITS are safe procedures for major and already for minor resections, technically eligible and successfully managed with combined regional blockades and intravenous sedation techniques. Patients remain stable throughout the procedures, without severe hypoxemia or hypercapnia, cough reflex can be stopped effectively with vagal blockade. If tracheal intubation is needed due to anesthesiological or surgical reasons it can be performed fast and safely with ensure of maximal patient safety.

Although the long-term benefits still remained unclear, we suggest that thoracic procedures with spontaneously breathing patient can potentially be an attractive alternative of intubated one-lung ventilated thoracoscopic surgery. The VATS-SVI can be a new alternative method in the modern era with reduced ventilated time and less potential complications of mechanical ventilation. Extensive experience in routine procedures in thoracic surgery is the basis and completed with adequate training of non-intubated VATS surgery will be essential. This beneficial combination of surgical and anaesthetic techniques combination is on the fast-track service to become an essential and fully reliable tool opportunity within thoracic surgery programs.

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