Research Article

Single-Lumen Endotracheal Ventilation With Capnothorax For Prone Thoracoscopic Esophageal Surgery: Anesthetic Management In A Case Series of Three Patients

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Abstract

Introduction: One-lung ventilation (OLV) through a double-lumen tube is the conventional technique for thoracoscopic esophageal surgery, but it carries risks of hypoxemia, airway trauma and tube malposition. Two-lung ventilation through a single-lumen tube combined with controlled CO_2 insufflation (capnothorax) has been proposed as an alternative, particularly in the prone position.

Case presentation: We describe three patients who underwent prone video-assisted thoracoscopic surgery (VATS) for esophageal lesions: a 17-year-old girl with an esophageal duplication cyst, a severely undernourished 60-year-old man (BMI 14.8 kg/m²) with esophageal carcinoma undergoing esophagectomy, and a 45-year-old woman with an esophageal gastrointestinal stromal tumor (GIST). All were managed with a single-lumen endotracheal tube, gravity-assisted lung displacement in the prone position, controlled CO_2 insufflation, and low-tidal-volume ventilation with permissive hypercapnia (maximum recorded end-tidal CO_2 42–45 mmHg). Regional analgesia (erector spinae plane block or thoracic epidural) was used in two patients. Surgical exposure was adequate in all cases without conversion to OLV; no clinically significant desaturation or hemodynamic instability occurred, all patients were extubated in the operating room, and recovery was uneventful.

Conclusion: In these selected patients, single-lumen ventilation with capnothorax was feasible for prone thoracoscopic esophageal surgery. Given the small, heterogeneous sample and exclusive use of the prone position, these observations are hypothesis-generating and do not establish the technique as an equivalent alternative to OLV; controlled studies, including in the lateral decubitus position, are needed.

Keywords: Capnothorax; Esophageal neoplasms; Intratracheal intubation; One-lung ventilation; Prone position; Thoracic surgery, video-assisted.

Introduction

Minimally invasive thoracoscopic surgery has become an established approach for esophageal lesions, offering less postoperative pain, fewer pulmonary complications and shorter hospital stay than open thoracotomy [1,2]. Surgical exposure has traditionally been obtained with one-lung ventilation (OLV) using a double-lumen tube (DLT) or bronchial blocker. However, OLV is associated with hypoxemia, ventilator-induced injury to the ventilated lung, airway trauma, tube malposition (especially after repositioning) and hemodynamic disturbance, and these risks are amplified in patients with limited cardiopulmonary or nutritional reserve [3].

In the prone position, gravity displaces the lung anteriorly, away from the posterior mediastinum, and this effect can be augmented by low-pressure CO_2 insufflation of the pleural cavity (capnothorax) [1]. This has allowed thoracoscopic esophageal dissection to be performed with two-lung ventilation through a conventional single-lumen endotracheal tube, avoiding lung isolation altogether [4–6]. Comparative data, however, come largely from esophagectomy for cancer, and reports describing the anesthetic conduct of this technique across different esophageal pathologies remain few.

Esophageal lesions pose specific anesthetic challenges because of their mediastinal location, proximity to the airway and great vessels, aspiration risk, and the frequent coexistence of dysphagia-related malnutrition [3]. Some of these lesions are themselves uncommon: esophageal duplication cysts are rare foregut malformations [7], and the esophagus is the least frequent site of gastrointestinal stromal tumors (GISTs) [8]. We report three patients with an esophageal duplication cyst, an esophageal carcinoma and an esophageal GIST who underwent prone thoracoscopic

surgery with single-lumen endotracheal ventilation and capnothorax. Each case is described in a standardized format in accordance with the CARE reporting guidelines [9], and we discuss what this limited experience adds to the existing evidence on avoiding OLV in thoracoscopic esophageal surgery.

Case Presentations

Case 1: Esophageal duplication cyst

Patient information. A 17-year-old girl (weight 44 kg, height 157 cm, BMI 17.9 kg/m²) with a known seizure disorder controlled on regular antiepileptic therapy.

Clinical findings and diagnosis. She presented with abdominal pain, nausea and dysphagia. Contrast-enhanced computed tomography (CT) of the chest and abdomen showed a well-defined 2.3 × 1.9 cm soft-tissue lesion arising from the right lateral aspect of the mid-esophagus at the level of the T9 vertebra in the posterior mediastinum, consistent with an esophageal duplication cyst.

Preoperative assessment. Routine laboratory investigations, electrocardiography (ECG) and echocardiography were within normal limits. Neurology consultation was obtained for perioperative seizure management. After counseling, she was scheduled for thoracoscopic excision of the cyst.

Anesthetic technique. Standard ASA monitoring (ECG, non-invasive blood pressure, pulse oximetry and capnography) was applied. After premedication with intravenous midazolam and glycopyrrolate, anesthesia was induced with fentanyl 2 µg/kg and propofol 2 mg/kg. Once mask ventilation was confirmed, atracurium 0.5 mg/kg was administered and the trachea was intubated with a 7.0 mm single-lumen endotracheal tube; bilateral air entry was confirmed. Anesthesia was maintained with sevoflurane 1–2% in a 50:50 oxygen–nitrous oxide mixture using volume-controlled ventilation. After the patient was turned prone, an ultrasound-guided right erector spinae plane (ESP) block was performed at T5 with 20 mL of 0.25% bupivacaine and dexamethasone 4 mg.

Surgical approach. With the patient prone, the lung fell anteriorly under gravity, away from the posterior mediastinum. Thoracoscopic ports were inserted and CO_2 was insufflated into the right pleural cavity to create a capnothorax and complete the exposure (Figure 1). The cyst was dissected free of the esophageal wall and excised. Surgical duration was approximately 2 hours 40 minutes.

Ventilation strategy. During capnothorax, volume-controlled ventilation was continued with a low tidal volume and low respiratory rate, accepting permissive hypercapnia; end-tidal CO_2 ($EtCO_2$) peaked at 42 mmHg. CO_2 insufflation was established gradually and maintained at low pressure in coordination with the surgical team.

Intraoperative course. There was no clinically significant hemodynamic instability or desaturation. Exposure was adequate throughout and conversion to OLV was not required.

Outcome. She was extubated in the operating room and transferred to the intensive care unit (ICU) for observation. Analgesia was satisfactory and the postoperative course was uneventful.

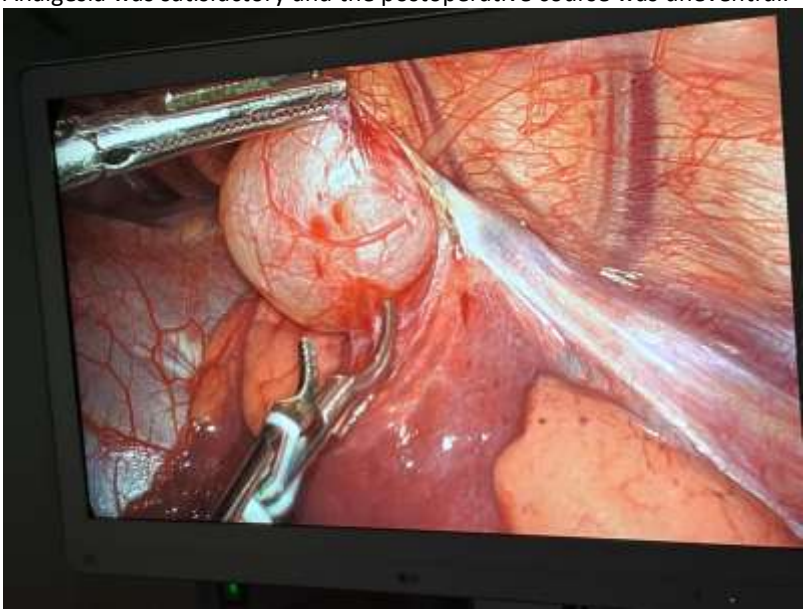


Figure 1. Thoracoscopic view (prone position, right hemithorax) of the esophageal duplication cyst: the smooth,

well-circumscribed cyst is grasped and dissected from the esophageal wall, with the collapsed lung visible in the lower right of the field.

Case 2: Esophageal carcinoma

Patient information. A 60-year-old man (weight 38 kg, height 160 cm, BMI 14.8 kg/m²) with no significant past medical history but severe undernutrition.

Clinical findings and diagnosis. He presented with progressive dysphagia to solids and liquids, vomiting and fatigue. Upper gastrointestinal endoscopy showed a growth 26 cm from the incisors; biopsy confirmed esophageal carcinoma. Positron emission tomography–CT showed localized disease without distant metastasis.

Preoperative assessment. Two-dimensional echocardiography and other preoperative investigations were unremarkable. After detailed evaluation and informed consent, he was scheduled for thoracoscopic esophagectomy with gastric pull-up.

Anesthetic technique. A thoracic epidural catheter was placed at T9 under aseptic precautions before induction for intra- and postoperative analgesia. After preoxygenation and premedication with midazolam and glycopyrrolate, anesthesia was induced with fentanyl 2 μg/kg and propofol 2 mg/kg, and vecuronium 0.1 mg/kg was given for neuromuscular blockade. The trachea was intubated with a 7.5 mm single-lumen endotracheal tube and bilateral breath sounds were confirmed. Anesthesia was maintained with sevoflurane 1–2% in 50:50 oxygen–nitrous oxide with volume-controlled ventilation.

Surgical approach. The thoracoscopic phase was performed prone, with ports inserted after gravity-assisted displacement of the lung and CO_2 insufflation to create a capnothorax (Figure 2). The patient was then turned supine for the abdominal phase and gastric pull-up. Total surgical duration was approximately 4 hours.

Ventilation strategy. Low-tidal-volume ventilation was used, with the respiratory rate adjusted to $EtCO_2$, which peaked at 45 mmHg during the thoracoscopic phase. CO_2 insufflation was introduced gradually and kept at low pressure throughout the thoracoscopic phase.

Intraoperative course. Hemodynamic and respiratory parameters remained stable during both the prone and supine phases. No significant desaturation occurred. Conversion to OLV was not required.

Outcome. He was extubated in the operating room and transferred to the ICU. The postoperative course was uneventful, with no pulmonary complications.



Figure 2. External view of thoracoscopic port placement with the patient in the prone position.

Case 3: Esophageal gastrointestinal stromal tumor

Patient information. A 45-year-old woman with no significant comorbidities and no reported weight loss.

Clinical findings and diagnosis. She presented with a 4-month history of progressive dysphagia to solids and mild retrosternal discomfort, without hematemesis or history of corrosive ingestion. Upper gastrointestinal endoscopy

revealed a submucosal bulge in the mid-esophagus, and contrast-enhanced CT showed a localized esophageal lesion without nodal involvement or distant metastasis. Biopsy confirmed a GIST with positive c-KIT (CD117) immunostaining.

Preoperative assessment. Preoperative investigations were within normal limits. With written informed consent, she was scheduled for thoracoscopic resection of the mass.

Anesthetic technique. Monitoring comprised ECG, pulse oximetry, capnography and invasive arterial pressure. Anesthesia was induced with fentanyl 2 µg/kg and propofol 2 mg/kg, and atracurium 0.5 mg/kg was given for neuromuscular blockade. The airway was secured with a 7.5 mm cuffed single-lumen endotracheal tube, and anesthesia was maintained with sevoflurane 1–2% in 50:50 oxygen–nitrous oxide with volume-controlled ventilation.

Surgical approach. With the patient prone, ports were placed after gravity-assisted lung displacement, and a capnothorax was established by controlled CO_2 insufflation (Figure 3). Surgical duration was approximately 3 hours.

Ventilation strategy. After establishment of the capnothorax, ventilation was changed to pressure-controlled mode with low tidal volumes and a high FiO_2. Brief periods of apnea were provided at the surgeon's request to improve visualization during critical dissection, and SpO_2 was maintained above 94% with permissive hypercapnia. CO_2 insufflation was introduced gradually and maintained at low pressure.

Intraoperative course. Hemodynamic parameters remained stable throughout, with SpO_2 consistently above 94%. Conversion to OLV was not required.

Outcome. She was extubated in the operating room and transferred to the post-anesthesia recovery unit. The postoperative course was uneventful.



Figure 3. Thoracoscopic view during mediastinal dissection in the prone position, with the lung displaced away from the operative field under capnothorax.

Clinical characteristics, anesthetic management and outcomes of the three patients are summarized in Table 1.

Table 1. Summary of patient characteristics, anesthetic management and outcomes

Parameter	Case 1	Case 2	Case 3
Age / sex	17 years / F	60 years / M	45 years / F
Weight; BMI	44 kg; 17.9 kg/m²	38 kg; 14.8 kg/m²	NR
Comorbidity	Seizure disorder on antiepileptics	None; severe undernutrition	None reported
Lesion / level	Duplication cyst, 2.3 × 1.9 cm, mid-esophagus (T9)	Carcinoma, 26 cm from incisors	GIST (c-KIT+), mid-esophagus
Procedure	Thoracoscopic excision of cyst	Thoracoscopic–abdominal esophagectomy with gastric pull-up	Thoracoscopic resection of mass

Parameter	Case 1	Case 2	Case 3
Airway	7.0 mm single-lumen ETT	7.5 mm single-lumen ETT	7.5 mm cuffed single-lumen ETT
Induction / NMB	Fentanyl, propofol / atracurium	Fentanyl, propofol / vecuronium	Fentanyl, propofol / atracurium
Maintenance	O_2:N_2O 50:50 + sevoflurane 1–2%	O_2:N_2O 50:50 + sevoflurane 1–2%	O_2:N_2O 50:50 + sevoflurane 1–2%
Ventilation during capnothorax	VCV, low VT, low RR	VCV, low VT, RR titrated to $EtCO_2$	PCV, low VT, high FiO_2, intermittent apnea
Maximum $EtCO_2$	42 mmHg	45 mmHg	NR
Oxygenation	No significant desaturation	No significant desaturation	SpO_2 >94% throughout
Regional analgesia	Right ESP block, T5	Thoracic epidural, T9	None
Surgical duration	≈2 h 40 min	≈4 h	≈3 h
Conversion to OLV	No	No	No
Extubation / disposition	In OR / ICU	In OR / ICU	In OR / recovery unit
Postoperative complications	None	None	None

BMI, body mass index; ESP, erector spinae plane; ETT, endotracheal tube; $EtCO_2$, end-tidal CO_2; GIST, gastrointestinal stromal tumor; ICU, intensive care unit; NMB, neuromuscular blocker; NR, not reported; OLV, one-lung ventilation; OR, operating room; PCV, pressure-controlled ventilation; RR, respiratory rate; VCV, volume-controlled ventilation; VT, tidal volume.

Discussion

In this series of three heterogeneous patients — an adolescent with a benign duplication cyst, a severely undernourished older man undergoing esophagectomy, and a woman with an esophageal GIST — thoracoscopic esophageal surgery was performed in the prone position with a single-lumen endotracheal tube, two-lung ventilation and controlled capnothorax. Despite differences in age, pathology, extent of surgery and physiological reserve, exposure was adequate in every case, no patient required conversion to OLV, gas exchange and hemodynamics remained acceptable, and all three were extubated in the operating room without postoperative respiratory complications.

Physiological basis of the technique

The prone position is central to this approach. Gravity displaces the right lung anteriorly, away from the posterior mediastinum, while blood and irrigation fluid pool away from the operative field [1]. Low-pressure CO_2 insufflation further compresses the lung and widens the mediastinal working space, so that adequate exposure can be achieved without lung isolation [4]. Because both lungs continue to be ventilated, intrapulmonary shunt is lower than with OLV, and the hazards specific to DLTs and bronchial blockers — airway and bronchial injury, malposition after turning the patient prone, and the need for tube exchange if postoperative ventilation is required — are avoided [2,3]. These advantages are particularly relevant to patients such as Case 2, whose severe undernutrition limited respiratory reserve, and to smaller patients such as Case 1, in whom DLT sizing and placement can be more difficult.

Ventilation strategy

Once the capnothorax was established, we used low tidal volumes with the respiratory rate titrated to $EtCO_2$ and oxygenation; in Case 3, pressure-controlled ventilation and brief apneic periods were added to optimize exposure, with saturation maintained above 94%. Artificial pneumothorax during two-lung ventilation in the prone position measurably alters respiratory mechanics, with reduced compliance and higher airway pressures [10], and lung-

protective low-tidal-volume ventilation with acceptance of moderate hypercapnia is the usual response [4,6]. The mild hypercapnia observed in our patients (maximum $EtCO_2$ 42–45 mmHg in the two cases with complete records) did not cause hemodynamic or clinical acid–base derangement. The partial pressure gradient between $EtCO_2$ and arterial CO_2 can widen during capnothorax, so arterial blood gas monitoring is advisable during prolonged procedures.

Comparison with published experience

Our observations are consistent with previous reports, most of which concern minimally invasive esophagectomy for cancer. Singh et al. described the successful use of a single-lumen tube with gravity-assisted lung collapse and CO_2 insufflation in prone minimally invasive and hybrid esophagectomies [11], and Bai et al. reported single-lumen tracheal ventilation to be a safe and effective option for minimally invasive esophagectomy in patients with esophageal cancer [12]. A meta-analysis by Chuang et al. found that single-lumen intubation with artificial CO_2 pneumothorax was associated with fewer surgical and postoperative pulmonary complications than DLT-based OLV [5], and reviews comparing two-lung ventilation under artificial pneumothorax with OLV have reported better oxygenation with comparable hemodynamics [4,6]. The present series adds descriptive anesthetic detail for two non-malignant or uncommon esophageal pathologies — a duplication cyst and a GIST — in which the extent of dissection is smaller than in esophagectomy, and suggests that the same strategy may be applicable beyond cancer surgery.

Analgesia and early extubation

Regional analgesia — an ESP block in Case 1 and a thoracic epidural in Case 2 — probably contributed to smooth emergence and immediate extubation. The ESP block is technically simple, can be performed after the patient is turned prone, and is an attractive alternative when neuraxial techniques are undesirable [13], whereas thoracic epidural analgesia remains a cornerstone of enhanced recovery after esophagectomy [14]. Avoidance of OLV and of DLT-related airway trauma may also have facilitated early extubation, although the contribution of each factor cannot be separated in this series.

Risks and patient selection

These findings must be weighed against the physiological risks of capnothorax. Rapid or excessive insufflation raises intrathoracic pressure, impairs venous return and cardiac output, increases airway pressure and can cause hypotension and desaturation; CO_2 absorption adds to the ventilatory load, and gas embolism, though rare, is possible [15,16]. Insufflation should therefore begin at low flow and low pressure and be increased gradually under continuous observation of blood pressure, airway pressure and $EtCO_2$. Success also depends on adequate lung displacement: pleural adhesions, distorted anatomy or dense fibrosis may prevent it, and a DLT or bronchial blocker should be immediately available for conversion. Patients with severe chronic obstructive pulmonary disease, restrictive lung disease, pulmonary hypertension or limited cardiac reserve may tolerate capnothorax poorly; in such patients invasive arterial monitoring, serial blood gas analysis and a low threshold for conversion to lung isolation are warranted. Finally, nitrous oxide was used in all three cases as part of our institutional practice. Because it reduces the achievable FiO_2 and can diffuse into gas-filled spaces, an air–oxygen mixture may be preferable during capnothorax, particularly when oxygenation is marginal or a gastric conduit is being fashioned.

Limitations

This report has important limitations. First, three cases cannot establish the safety or efficacy of this technique; the findings are descriptive and hypothesis-generating only. Second, the cases were heterogeneous in pathology (benign cyst, carcinoma and GIST), extent of surgery and anesthetic technique — an ESP block in Case 1, a thoracic epidural in Case 2, and pressure-controlled ventilation with intermittent apnea in Case 3 — each a potential confounder that precludes attributing the observed stability to the ventilation strategy alone. Third, all procedures were performed prone, a position that itself assists lung displacement by gravity; the findings may therefore not apply to surgery in the lateral decubitus position. Fourth, the data were obtained retrospectively from anesthesia records, there was no comparison group, and only short-term outcomes were assessed. Finally, several intraoperative parameters — exact ventilator settings, CO_2 insufflation pressures and flow rates, and continuous hemodynamic ranges — were not available for reporting, which limits the reproducibility of the technique.

Conclusion

In three selected patients undergoing prone thoracoscopic surgery for esophageal lesions, anesthetic management with a single-lumen endotracheal tube, controlled capnothorax and low-tidal-volume two-lung ventilation was feasible, with acceptable intraoperative gas exchange and hemodynamics and uncomplicated early extubation. Given the small, heterogeneous sample and exclusive use of the prone position, this experience supports further study rather than adoption of the technique as a general alternative to OLV. Careful patient selection, gradual and monitored CO_2 insufflation, an adaptable ventilatory strategy, readiness to convert to lung isolation, and close surgeon–anesthesiologist communication are central to its safe use, and larger comparative studies are needed.

Learning Points

- In the prone position, gravity-assisted lung displacement combined with low-pressure CO_2 insufflation can provide adequate thoracoscopic exposure of the esophagus without lung isolation.
- Low-tidal-volume ventilation with permissive hypercapnia, and brief apneic periods when needed, maintain acceptable gas exchange during capnothorax.
- Insufflation should be started at low pressure and increased gradually, with close attention to blood pressure, airway pressure and $EtCO_2$.
- Equipment for lung isolation should be immediately available, and patients with limited cardiopulmonary reserve need invasive monitoring and a low threshold for conversion.

Declarations

Ethics approval: This case series was approved by the Institutional Ethics Committee, Sree Balaji Medical College and Hospital (SBMCH), Chennai, Tamil Nadu, India

Consent for publication: Written informed consent for publication of clinical details and images was obtained from all patients; for the patient in Case 1, who was a minor, consent was obtained from a parent/legal guardian together with the patient's assent.

Conflicts of interest: The authors declare no conflicts of interest.

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Author contributions: All authors contributed to patient management, data collection, literature review, drafting and critical revision of the manuscript, and approved the final version.

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Data availability: All relevant data are included in this article.

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