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THE ROLE OF PRESERVED SPONTANEOUS BREATHING DURING THORACIC SURGERY

PhD Thesis

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International publications on which the PhD thesis is based

1. Szabo Zsolt, **Fabo Csongor**, Oszlanyi Adam, Hawchar Fatime, Geczi Tibor, Lantos Judit, Furak Jozsef: Anesthetic (r)evolution from the conventional concept to the minimally invasive techniques in thoracic surgery-narrative review JOURNAL OF THORACIC DISEASE 14 : 8 pp., 16 p. (2022); SJR indicator: Q2
2. Szabo, Z.; **Fabo, C.**; Szarvas, M.; Matuz, M.; Oszlanyi, A.; Farkas, A.; Paroczai, D.; Lantos, J.; Furak, J. Spontaneous Ventilation Combined with Double-Lumen Tube Intubation during Thoracic Surgery: A New Anesthesiologic Method Based on 141 Cases over Three Years. J. Clin. Med. 2023, 12, 6457. SJR indicator: Q1

International and Hungarian publications related to the topic of the PhD thesis

3. Furák József, Németh Tibor, Lantos Judit, **Fabó Csongor**, Géczi Tibor, Zombori-Tóth Noémi, Paróczai Dóra, Szántó Zalán, Szabó Zsolt: Perioperative Systemic Inflammation in Lung Cancer Surgery FRONTIERS IN SURGERY 9 Paper: 883322, 7 p. (2022) SJR indicator: Q2
4. **Fabo Csongor**, Oszlanyi Adam, Lantos Judit, Rarosi Ferenc, Horvath Theodor, Barta Zsanett, Nemeth Tibor, Szabo Zsolt: Nonintubated Thoracoscopic Surgery-Tips and Tricks From Anesthesiological Aspects: A Mini Review FRONTIERS IN SURGERY 8 Paper: 818456, 8 p. (2022) SJR indicator: Q2

5. **Fabo Csongor**, Oszlanyi Adam, Barta Zsanett Virág, Nemeth Tibor, Lantos Judit, Vaida Stefan Nicolae, Szabo Zsolt: Anesthesiology of the spontaneous ventilation in thoracic surgery: a narrative review AME Surgical Journal 2 Paper: 14, 7 p. (2022)
6. Furák József, Barta Zsanett, Lantos Judit, Németh Tibor, Pécsy Balázs, Buzás András, Vas Márton, **Fabó Csongor**, Szabó Zsolt, Rieth Anna, Lázár György: Intubálással biztosított spontán légzés módszerével elvégzett sublobaris tüdőreszekciók korai műtét utáni eredményei. Új műtéti eljárás MAGYAR SEBÉSZET 75 : 2 pp. 117-120., 4 p. (2022)
7. Farkas A, Csókási T, **Fabó C**, Szabó Z, Lantos J, Pécsy B, Lázár G, Rárosi F, Kecskés L and Furák J (2023) Chronic postoperative pain after nonintubated uniportal VATS lobectomy. Front. Surg. 10: 1282937. (2023) SJR indicator: Q2
8. Furák J, Németh T, Budai K, Farkas A, Lantos J, Glenz JR, **Fabó C**, Shadmanian A, Buzás A. Spontaneous ventilation with double-lumen tube intubation for video-assisted thoracic surgery thymectomy: a pilot study. Video-assist. Thorac Surg: 8p (2023) SJR indicator: Q4

1. Introduction

High-risk surgical interventions such as thoracic procedures come with an increased risk of morbidity and mortality, which is more pronounced in frail patients with severe comorbidities. Enhanced Recovery After Surgery (ERAS) is a set of guidelines focused on integrating preoperative preparation, minimally invasive surgical and anesthetic methods, and postoperative care to improve patient outcomes. [3,4]

The video-assisted thoracic surgery (VATS) technique combines the advantages of minimally invasive interventions with an optimal view of the surgical field. [5] Traditionally, thoracic procedures require(d) general anesthesia, muscle relaxation, and controlled mechanical one-lung ventilation (mOLV). The functional separation of the lungs can be achieved with double-lumen tube (DLT) insertion or by bronchial blockers (BB). General anesthesia, muscle relaxation, and endotracheal intubation enhance the risk of pulmonary complications. The POPULAR study demonstrated that the use of neuromuscular blocking agents (NMBAs) during general anesthesia increases the risk of post-anesthesia pulmonary complications (PPCs) [10].

The stress experienced by the patient's body during surgical interventions essentially consists of two components: those associated with the surgical insult and the detrimental effects induced by anesthesia. The effects of minimally invasive surgical approaches have been widely investigated, and VATS is associated with a lower postoperative complication rate than the open approach [12]. Minimally invasive surgical and anesthetic approaches, such as VATS, which has proven superior to thoracotomy also offer immunological advantages. [13] As a significant portion of the interventions is performed using the VATS method, further progress is expected from the minimally invasive anesthesiological techniques.

2. Open points

Due to the paradigm shift that occurred in the last decades in the field of thoracic surgery and thoracic anesthesia, minimally invasive techniques have become more and more frequently applied. Bringing maintained spontaneous breathing to the fore has provided certainty about its relevance in thoracic anesthesia, although it has also raised some questions, and risks and concerns related to the non-intubated technique have also been identified. The main concern appears to be the question of the safe airway. This problem can possibly be resolved with the SVI method as we use double-lumen endotracheal tube for intubation with maintained spontaneous breathing.

1. Is there a non-intubated technique that allows conventional anesthesiological interventions (lung recruitment, fiberoptic manipulation, water submersion test) to be performed safely?
2. Is the use of the SVI technique a safe and feasible alternative to the gold standard method in thoracic anesthesia?
3. Is the SVI technique suitable for patients who are not candidates for a NITS procedure according to the applied exclusion criteria of NITS?
4. Is the SVI technique associated with temporary or permanent gas exchange abnormalities and/or acid-base disturbances?
5. Comparison of the intra- and early postoperative results of thoracic surgeries performed with SVI with data from the literature.

3. Research aims and objectives

I. In the first narrative review published by us, we intended to survey the development of thoracic anesthesia, focusing primarily on the advantages and disadvantages of anesthetic techniques applied by different workgroups for spontaneous breathing thoracic procedures.

II. Secondly, in our prospective, nonconsequential case series, we investigated the intra- and early postoperative results of thoracic surgeries performed with SVI (maintained spontaneous breathing with double-lumen tube intubation), as well as the safety and feasibility of this anesthetic strategy, with specific focus on the intraoperative oxygenation, carbon dioxide removal, and the consequent acid-base disturbances.

We aimed to assess the following:

1. Can the SVI technique be a safe and feasible method for various types of thoracic procedures (minor and major resections)?
2. Can SVI reduce the mechanical ventilation time or alter the applied ventilation parameters?
3. Are there any differences in the intraoperative parameters (oxygenation, carbon dioxide removal, acid-base disturbances, hemodynamic parameters) compared with the gold standard and NITS methods?
4. Is SVI a useful and safe alternative if surgical conversion (thoracotomy) becomes necessary?

4. Study I.

4.1. Materials and methods

Multiple medical literature databases (PubMed, Google Scholar, Scopus) were searched, using the terms [(non-intubated) OR (non-intubated) OR (tubeless) OR (awake)] AND (thoracoscopic surgery)] as well as their Medical Subject Headings (MeSH) terms from 2004 to December 2021. Three hundred and six scientific papers were collected. The editorials, commentaries, and letters were excluded, similarly to papers focusing on topics other than the non-intubated (also known as awake or tubeless) VATS technique, as well as the full text scientific papers available in languages other than English. After all this, 36 articles were included.

4.2. Results

Based on the literature data, preserving spontaneous breathing can diminish the potential harmful effect of the conventional approach, but it is very important to emphasize that SB during thoracic procedures can be dangerous due to unusual circumstances (i.e., paradoxical breathing, mediastinal movement). This explains why the inclusion of NIVATS in the training programs for professional perioperative teams is essential to ensure maximal patient safety and comfort for the teams. [83,84] After reviewing the literature, we identified different methods with very similar clinical results. In Table 1, we summarize, the most relevant characteristics of the different anesthetic approaches.

Table 1. Cornerstones of anesthetic management in thoracic surgery

Method	Approach	Airway	Level of sedation	Drugs for sedation	Type of analgesia	Advantages	Limitations
Conventional		DLT, BB	BIS 40-60	Fentanyl Propofol / volatile anesthetic agents Muscle relaxant	TEA	Safe airway Isolated lungs Possibility of fibroscopy Possibility of lung recruitment	Intubation trauma Muscle relaxation Hemodynamic consequences of TEA
Italian	NIVATS	Facemask/ (LMA)	Awake, BIS- guided sedation	None / midazolam, remifentanil	TEA/ICB + aerosolized lidocaine	No muscle relaxation Maintained SB	No safe airway
Asian	NIVATS	Facemask/ THRIVE	BIS 40-60	Propofol	TEA/ICB + vagal blockade	No muscle relaxation Maintained SB	No safe airway
Hungarian	NIVATS	LMA	BIS 40–60	Midazolam, fentanyl, propofol	ICB, PVB + vagal blockade	No muscle relaxation Possibility of lung recruitment	Semi-safe airway
	VATS-SVI	DLT	BIS 40–60	Midazolam, fentanyl, propofol	ICB, PVB + vagal blockade	Safe airway SB after elimination of muscle relaxant Isolated lungs Possibility of fibroscopy and lung recruitment Higher BMI limit (< 32)	Intubation trauma Increased airway resistance
Other	NIVATS	Facemask	Light sedation	Midazolam, fentanyl	TEA + Stellate ganglion blockade	No muscle relaxation Maintained SB	No safe airway No DOA monitoring

DLT, double-lumen tube; BB, bronchial blocker; TEA, thoracic epidural anesthesia; NIVATS, non-intubated video-assisted thoracoscopic surgery; LMA, laryngeal mask airway; BIS, bi-spectral index; ICB, intercostal block; VATS-SVI, video-assisted thoracoscopic surgery with spontaneous ventilation combined with double-lumen tube intubation; THRIVE, transnasal humidified rapid-insufflation ventilatory exchange; PVB, paravertebral blockade; BMI, body mass index; DOA, depth of awareness; SB, spontaneous breathing

5. Study II.

5.1. Materials and methods

5.1.1. Study Design and Patient Selection

In our case series, the SVI method was applied in 141 cases between 10 March, 2020 and 28 October, 2022. For patient selection, we applied our previously published criteria for non-intubated thoracic procedures (Table 2).[79] From a surgical perspective, we included patients with no advanced lung cancer (< 7 cm, N0, or N1). [80]

Table 2. Exclusion criteria of spontaneous breathing anesthetic techniques.

NITS	SVI
Patient refusal or lack of compliance	Patient refusal
Elevated IC pressure	Elevated IC pressure
Sleep apnea syndrome	
Airway abnormalities, anticipated difficult airway	
BMI ≥ 34 kg/m^2	BMI ≥ 34 kg/m^2
Persistent cough or high airway secretion	
Elevated risk of regurgitation	
Coagulation abnormality, INR > 1.5	
Hemodynamic instability, RHF	Hemodynamic instability, RHF

NITS, non-intubated thoracic surgery; SVI, spontaneous ventilation combined with double-lumen tube intubation; BMI, body mass index; INR, International Normalized Ratio; RHF, right heart failure; IC, intracranial

5.1.2. Anesthetic management

Three-lead ECG, oxygen saturation (SpO_2), and invasive blood pressure were monitored, along with anesthesia depth using the bispectral index (BIS). Anesthesia was induced with fentanyl and propofol target-controlled infusion, targeting a BIS value of 40-60, and mivacurium chloride (0.1–0.15 µg/kg) was used for intubation. After opening the thoracic cavity, paravertebral and vagal blocks were applied for pain relief and cough prevention.

Rescue Maneuvers

Hypotension: According to our intraoperative hemodynamic management protocol, when the mean arterial pressure was < 60 mmHg, the systolic blood pressure was < 90 mmHg or decreased by more than 25%, ephedrine (5–10 mg) or phenylephrine (50–100 µg) was administered in divided doses.

Hypoxia / Hypercapnia / Technical Difficulties: We followed the anesthetic rescue strategy flowchart presented in Figure 1.

5.1.3 Regional Anesthetic Techniques

During VATS with SVI in routine cases, 5 mg/kg of lidocaine (2%) was administered at the site of incision at the fifth intercostal space in the mid-axillary line. After opening the thoracic cavity under thoracoscopic guidance, vagal /3–5 mL of bupivacaine (0.5%)/ and paravertebral /4–5 mL of bupivacaine (0.5%)/ blocks were performed.

5.1.4. Surgical Technique

We performed the same VATS uniportal method during the SVI procedures that we published in our NITS study [29,79] with indications based on the European Society of Thoracic Surgeons consensus report [6] and the recommendation of the NITS. [81,82]

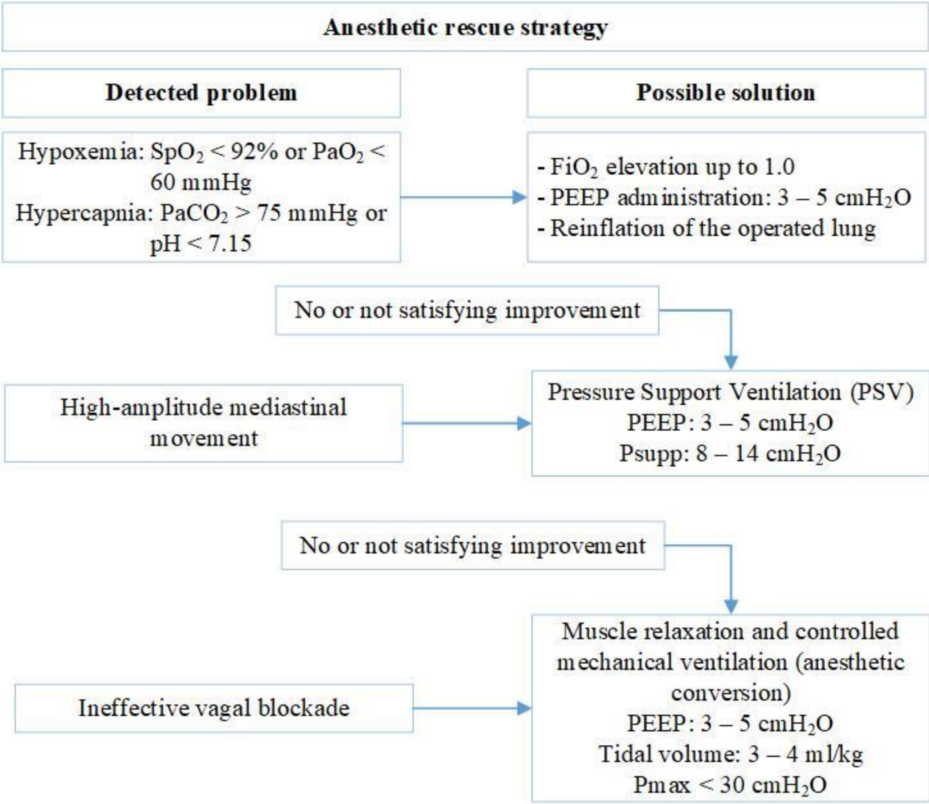


Figure 1 Anesthetic Rescue Strategy

5.1.5. Postoperative Care

Each patient was monitored in the PACU until discharge criteria were met (VAS < 3, Aldrete score > 9). Postoperative oxygen was administered via face mask at 4–6 L/min to maintain SpO2 levels above 94%, or above 88% for patients with COPD. Pain intensity was evaluated using the Numeric Pain Rating Scale (NPRS), with analgesic intervention initiated for scores exceeding 3. For thoracotomy patients, continuous local anesthetic (bupivacaine 0.33%, 0.1 mL/h/kg) was delivered via a pleural catheter

5.1.6. Arterial Blood Sampling

In the cases of major pulmonary resection, blood samples were collected four times (T1, T2, T3, and T4). For T1, preoperative blood samples were collected before anesthesia induction, with a FiO_2 of 0.21. For T2, steady-state blood samples were collected 15 min after the vagal nerve blockade. For T3, blood samples were collected 15 min after anatomical resection (and only during anatomical resections). For T4, postoperative blood samples were collected 30 min after the patient arrived in the recovery room, with an FiO_2 of 0.5.

5.2. Results

5.2.1. Patient Characteristics

A total of 67 (47.52%) of the patients were men, and 74 (52.48%) were female patients. The mean age was 62.13 years (19–83), with a mean BMI of 25.82 (15.79–38.54).

The mean Charlson Comorbidity Index was 5.51 (0–12). For the 91 patients whose FEV_1 values were available, the average was 82.45% (22.3%–126.4%). Among the 47 patients with DLCO data, the mean was

73.67% (35.3%–106%. The average surgical time was 80.6 minutes (25–150min). A total of 13 patients (9.22%) had previously undergone thoracic surgery. The surgical procedures were mainly lung resections (76 lobectomies, 22 segmentectomies, 25 wedge resections and 5 other procedures) and 13 thymectomies.

5.2.2. Anesthetic Results

In 93 patients (93/141, 65.96%), spontaneous respiration, with or without 3–5 cmH_2O PEEP administration, produced satisfactory gas exchange. In 44 cases (44/141, 31.21%), temporary or permanent PSV administration was necessary for supportive oxygenation and carbon dioxide removal (Table 3). In four cases (4/141, 2.84%), repeated muscle relaxation and a return to a conventional anesthetic pathway were necessary. (Table 3).

Table 3. Success of SVI and anesthetic conversions of SVI (N = 141).

Overall Success of SVI:	**N**	**%**
Spontaneous respiration with or without PEEP (non-PSV group)	93	65.96
Temporary/permanent pressure support ventilation (PSV group)	44	31.21
Anesthetic conversion (muscle relaxation, CMV)	4	2.84
Reasons for anesthetic conversion:	**N**	**%**
Intolerable mediastinal movement	1	0.71

Ineffective vagal blockade	2	1.42
DLT malposition	1	0.71

SVI, spontaneous ventilation combined with double-lumen tube intubation; PEEP, positive end-expiratory pressure; OLV, one-lung ventilation; DLT, double-lumen tube; CMV, controlled mechanical ventilation.

We compared the potentially relevant factors influencing the necessity of pressure support ventilation during an SVI procedure. The mean BMI was 26.9 (18.75–37.81) and 25.39 (15.79–38.54) in the PSV and in non-PSV groups, respectively. The incidence of asthma or COPD in the PSV group was 31.48% (14/44), and in the non-PSV group, it was 24.73% (23/93). According to the respiratory test parameters of limited availability, the mean FEV_1 (83.77% ± 18.35% vs. 75.71% ± 22.75%; $p = 0.043$) and DLCO (76.55% ± 16.04% vs. 65.89% ± 22.04%; $p = 0.044$) values were significantly lower in the PSV group than in the non-PSV group.

After anesthetic induction and 5–10 min following the vagal nerve blockade, hypotension was common. Of the 141 patients, 65 (46.1%) required phenylephrine or ephedrine due to hypotension. Ephedrine or phenylephrine administration was necessary in 49 cases (49/95, 51.58%) in patients with hypertension or other cardiovascular diseases (CV group), and it was administered for 15 patients (15/44, 34.09%) without any cardiovascular disease (non-CV group).

The mean one-lung ventilation time was 74.88 min (20–140 min). The mean mechanical and spontaneous OLV times were 17.55 min (0–115 min) and 57.73 min (0–100 min), respectively. The mechanical OLV time was reduced by 76.5%. (Table 4).

Table 4. Anesthesiologic parameters of SVI patients (N = 141).

	Mean	Median	Std. Deviation	Minimum	Maximum
HR min	64.84	65.00	12.432	39	90
HR max	84.91	83.00	14.314	52	130
Pre RRSys	126.93	125.00	22.199	80	180
Pre RRDias	74.37	70.00	14.108	38	120
Post RRSys	94.92	90.00	20.594	46	145
Post RRDias	57.25	60.00	12.784	26	94
OLV time	74.88	75.00	25.521	20	140
Mech. OLV time	17.55	15.00	17.245	0	115
Sp. OLV time	57.73	60.00	24.685	0	130
Sp. OLV/OLV (%)	76.539	80.952	19.714	0	100
SpO_2 Min	93.96	94.00	4.060	81	100
SpO_2 Max	99.18	100.00	1.254	94	100
Resp. R. Min	12.19	12.00	3.302	4	30

Resp. R. Max	19.19	18.00	4.659	6	36

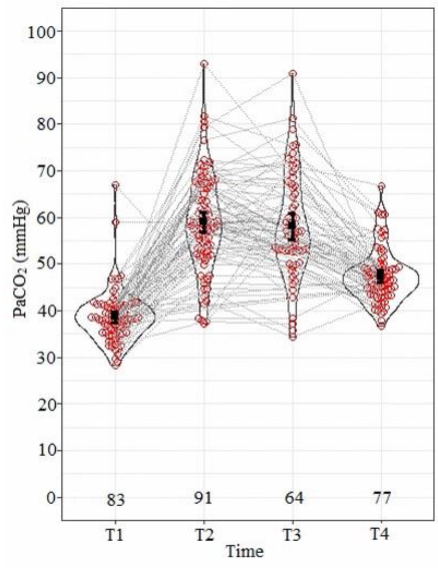
HR, heart rate; Pre RRSys, systolic blood pressure before vagal blockade; Pre RRDias, diastolic blood pressure before vagal blockade; Post RRSys, systolic blood pressure after vagal blockade; Post RRDias, diastolic blood pressure after vagal blockade; Mech. OLV, mechanical one-lung ventilation; Sp. OLV, spontaneous one-lung ventilation. OLV, one-lung ventilation; SpO_2, oxygen saturation; Resp. R, respiratory rate.

5.2.3. Blood Gas Results

According to the blood gas results, the mean PaO_2 level at time T2 was 115.97 mmHg (50.4–472.6 mmHg) and 143.831 mmHg (59.9–425.6 mmHg) at T3 (Table 5), and it was associated with a 93.96% (81–100%) mean minimal intraoperative oxygen saturation (Table 4). Hypercapnia, with or without respiratory acidosis, was a common but transient intraoperative complication. The mean $PaCO_2$ level at T2 was 59.05 mmHg (37.1–92.9 mmHg), with a mean pH of 7.27 (7.1–7.41). The mean $PaCO_2$ level at T3 was 58.17 mmHg (34.4–90.9 mmHg), accompanied by a mean pH of 7.27 (7.14–7.44). Hypercapnia and the acid-base discrepancy diminished in the early postoperative period. The mean $PaCO_2$ level at T4 was 47.44 mmHg (36.7–66.7 mmHg) (Table 5, Figure 2). Consequently, the mean pH was 7.332 (7.275–7.401) (Table 5, Figure 3). The mean intraoperative lactate level was 0.701 mmol/L (0.22–1.86 mmol/L) at T2 and 0.667 mmol/L (0.22–1.83 mmol/L) at T3.

Table 5. Blood gas results.

		Time	N	Mean	SD	Minimum	Maximum
FiO_2	1	preoperative	82	0.210	0.000	0.210	0.210
	2	steady state	89	0.821	0.200	0.500	1.000
	3	after resection	62	0.829	0.197	0.500	1.000
	4	postoperative	77	0.500	0.000	0.500	0.500
pH	1	preoperative	81	7.419	0.032	7.235	7.491
	2	steady state	90	7.270	0.054	7.100	7.412
	3	after resection	63	7.271	0.061	7.139	7.443
	4	postoperative	75	7.332	0.032	7.275	7.401
$PaCO_2$ (mmHg)	1	preoperative	83	38.619	5.642	28.300	66.900
	2	steady state	91	59.053	10.299	37.100	92.900
	3	after resection	64	58.167	11.293	34.400	90.900
	4	postoperative	77	47.438	5.670	36.700	66.700
PaO_2 (mmHg)	1	preoperative	81	79.459	11.519	57.900	130.700
	2	steady state	91	115.969	67.318	50.400	472.600
	3	after resection	64	143.831	78.665	59.900	425.600
	4	postoperative	77	149.543	55.581	48.600	262.100
Lactate (mmol/L)	1	preoperative	71	0.815	0.329	0.260	2.110
	2	steady state	72	0.701	0.322	0.220	1.860
	3	after resection	56	0.667	0.293	0.220	1.830
	4	postoperative	66	0.780	0.303	0.230	1.600



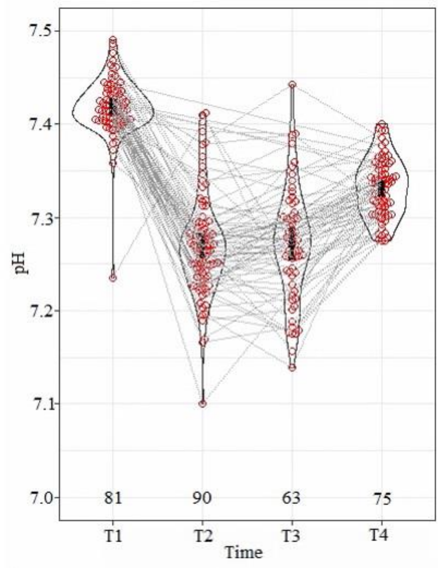


Figure 2 $PaCO_2$ levels

(Black square and lines: mean value ± 95% CI)

$PaCO_2$, partial pressure of carbon

Figure 3 pH levels

(Black square and lines: mean value ± 95% CI)

After surgery, all patients were extubated and transferred to the thoracic surgical ward after an average of 68.18 minutes in the recovery room. None required higher-flow oxygen, non-invasive ventilation, reintubation, or ICU admission. As part of multimodal pain management, 75 mg diclofenac was routinely given intraoperatively, with 25 of 141 patients needing no further analgesics. Postoperatively, 94 patients (66.67%) received metamizole, 83 (58.87%) received paracetamol, and

47 (33.33%) required both. Fentanyl (10–75 µg) was administered to 8 patients (5.67%) for adequate pain control, and tranexamic acid was needed in 1 case (0.71%) due to an elevated rate of bleeding.

5.2.4 Surgical Intraoperative Results

A total of 3 of the 141 surgeries were intended for open SVI procedures. In 12 additional cases (12/138, 8.70%), conversion to thoracotomy was necessary, without anesthetic conversion. Of these, 5 were due to oncological reasons (5/12, 41.67%), and 5 were due to technical difficulties (5/12, 41.67%). Bleeding also occurred in 2 cases (2/12, 16.67%). Overall, we performed 15 open thoracotomies (15/141, 10.64%) and 126 VATS (126/141, 89.36%) procedures. The mean operation time was 80.6 min (25–150 min) and 80.2 min (25–150 min) in all cases and in cases without anesthetic conversion, respectively. The mean length of hospital stay was found to be 4.8 days (1–26 days) in all cases.

6. Discussion

6.1. Airway management

One major concern with non-intubated thoracic procedures is the lack of double-lumen tube insertion and lung isolation. Initially, face masks were used, providing oxygen without positive end-expiratory pressure (PEEP) [26,91]. Asian workgroups then improved oxygenation and airway safety with transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) [93]. Our team introduced supraglottic devices (LMA), offering benefits such as PEEP application, lung recruitment maneuvers, and air leak detection via the water submersion test [29]. Despite ongoing protocol improvements, the method remains limited. Our new SVI approach combines double-lumen tube intubation with spontaneous breathing for enhanced airway safety and lung isolation

6.2. Sedation and regional anesthetic techniques

The early concept of non-intubated thoracic procedures avoided general anesthesia, as Italians performed operations on awake patients or using mild sedation with midazolam and remifentanil. Al Abdullatief's team used similar sedation with midazolam and fentanyl, along with thoracic epidural or intercostal blockade for pain relief [27,49]. Asian workgroups introduced BIS-guided propofol sedation, maintaining BIS levels between 40–60 for patient comfort, alongside thoracic epidural or intercostal blockade [106]. Cough prevention, key aspect in non-intubated procedures, was managed using techniques such as aerosolized lidocaine or vagal nerve blockade, with the latter becoming widespread due to ease of use [107]. Our NITS guideline emphasizes both patient comfort and safety, combining LMA, BIS-guided propofol sedation, and regional anesthesia. SVI follows the same protocol, with the addition of short-term muscle relaxation and DLT insertion for airway safety. Vagal nerve blockade (bupivacaine 2–5 mL) is used in both SVI and NITS to prevent coughing [27,79,108–110], and fentanyl is incrementally administered to control respiratory frequency. SVI combines the benefits of spontaneous breathing with DLT for maximum patient safety.

6.3. Anesthetic and surgical conversion

The riskiest part of NITS is the conversion process, occurring in 2–11% of cases [27,96,109,111–113], with difficult airways and intubation reaching up to 20%. Laryngeal masks enable emergency intubation, even in the lateral decubitus position, though difficult airways can still be challenging, while SVI offers a safer alternative by simplifying anesthetic conversion. From the surgeon's perspective, SVI and NITS are similar, though spontaneous ventilation surgeries present challenges due to mediastinal shifting and diaphragm movement. Shi et al.'s meta-analysis found these factors are the most common causes of anesthetic conversion (7% and 4%) [116]. Surgical conversion in both methods follows the same process and does not necessarily come with an anesthetic conversion [79]. In our SVI case series, the twelve surgical conversions from VATS SVI to open SVI were uneventful and when the indication for conversion is surgical (thoracotomy), muscle relaxation and controlled mechanical ventilation are not required

6.4. Gas exchange

Hypoxia and hypercapnia are common in NITS, with limited options to improve gas exchange [116]. In SVI, hypoxia can be managed with higher FiO_2, PEEP, or pressure support, while hypercapnia, caused by factors like mediastinal shifting and DLT use, can be controlled with pressure support ventilation. Hypercapnia usually resolves after lung reinflation [93,117–119]. According to our blood gas results collected 30 minutes after extubation during SVI procedures (T4), the mean $PaCO_2$ was 47.44 mmHg and the pH was 7.332. Hypercapnia may improve V/Q matching and reduce lung injury by suppressing inflammation [120,121]. Furák et al. found SVI to be more physiological for gas exchange, with better oxygenation and $PaCO_2$ levels compared to NITS [104]

6.5. Hemodynamics

During spontaneous breathing thoracic procedures, hemodynamics are influenced by various factors. The absence of positive pressure ventilation (PPV) results in less fluctuation in airway pressure, preload, and stroke volume [65]. However, surgical pneumothorax can affect cardiac preload and afterload. SVI offers better hemodynamic stability compared to non-intubated techniques [104]. In our SVI series, 46.1% of patients required temporary pharmacological support due to hypotension after anesthesia induction and vagal nerve blockades. Hypotension was more common in the CV group, largely due to medications such as beta-blockers and antihypertensives. Reduced mechanical one-lung ventilation time (76.5%) in SVI suggests less oxidative stress and potential hemodynamic and immunological benefits [57,122–124].

7. Conclusion

In recent decades, advancements like video-assisted thoracoscopy, uniportal techniques, and improved surgical instrumentation have greatly expanded minimally invasive surgical and anesthetic techniques. This thesis focuses on various minimally invasive anesthesiological strategies aimed at reducing surgical stress. Our practice includes BIS-guided propofol TCI sedation and LMA use, which supports key thoracic interventions and enhances patient safety while allowing anesthesiologists to utilize a broader range of techniques.

To improve patient safety and reduce exclusions from spontaneous breathing thoracic surgeries, we developed the SVI technique, combining NITS and traditional methods. SVI offers the benefits of minimally invasive anesthesia with the safety of conventional approaches, demonstrating low anesthetic conversion rates, normal oxygenation, and moderate hypercapnia without significant hemodynamic issues. Our results suggest SVI positively impacts patient outcomes, though further large-scale randomized trials are needed for comparison with conventional methods.

Both conventional intubated techniques, NITS, and SVI have their roles in anesthesiology, emphasizing the importance of tailoring the anesthetic strategy to individual patient needs.

8. New findings of the thesis

Study I.

1. Our method of NITS with BIS-guided propofol TCI and LMA is a novel, safe, and feasible technique, with the opportunity for lung recruitment, fiberoptic manipulation, and water submersion testing.

Study II.

1. SVI is a novel anesthetic technique in thoracic anesthesia, which combines maximal airway (patient) safety by double-lumen tube intubation with the preservation of spontaneous breathing activity. The SVI technique is safe and feasible for various types of thoracic procedures from wedge resections to major anatomical pulmonary resections (segmentectomies, lobectomies) and also for thymectomies. The SVI technique can be applied to a boarder range of patients than NITS as SVI has significantly fewer exclusion criteria.

2. By applying the SVI technique, the duration of controlled positive pressure ventilation during thoracic surgery can be reduced by 76.5%. Approximately two thirds of our patients had satisfactory gas exchange by spontaneous breathing with or without 3-5 cmH_2O PEEP administration, and one third of our patients needed temporary or permanent pressure support ventilation during the procedures, most commonly due to hypercapnia or high-amplitude mediastinal movement.

3. Oxygenation is within the normal range during SVI procedures, while permissive hypercapnia and the consequent acid-base disturbances are

temporary and resolve spontaneously in the early postoperative period, similarly to the gold standard procedure.

4. The SVI technique can be safely applied even in cases where thoracotomy becomes necessary due to surgical difficulties or oncological reasons. Surgical conversion (from VATS to open) does not result in a mandatory anesthetic conversion (from SVI to relaxed) – SVI shows a low anesthetic conversion rate (2.8%).

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