Liu *et al. BMC Anesthesiology* (2025) 25:7
https://doi.org/10.1186/s12871-024-02879-x

BMC Anesthesiology

RESEARCH

Open Access

Clinical practice of one-lung ventilation in mainland China: a nationwide questionnaire survey

Hong-jin Liu[1†], Yong Lin[1†], Wang Li[4], Hai Yang[5], Wen-yue Kang[6], Pei-lei Guo[7], Xiao-hui Guo[8], Ning-ning Cheng[9], Jie-chao Tan[10], Yi-na He[11], Si-si Chen[12], Yan Mu[13], Xian-wen Liu[14], Hui Zhang[3*] and Mei-fang Chen[1,2*]

Abstract

Background Limited information is available regarding the application of lung-protective ventilation strategies during one-lung ventilation (OLV) across mainland China. A nationwide questionnaire survey was conducted to investigate this issue in current clinical practice.

Methods The survey covered various aspects, including respondent demographics, the establishment and maintenance of OLV, intraoperative monitoring standards, and complications associated with OLV.

Results Five hundred forty-three valid responses were collected from all provinces in mainland China. Volume control ventilation mode, 4 to 6 mL per kilogram of predictive body weight, pure oxygen inspiration, and a low-level positive end-expiratory pressure ≤ 5 cm H_2O were the most popular ventilation parameters. The most common thresholds of intraoperative respiration monitoring were peripheral oxygen saturation (SpO_2) of 90–94%, end-tidal CO_2 of 45 to 55 mm Hg, and an airway pressure of 30 to 34 cm H_2O. Recruitment maneuvers were traditionally performed by 94% of the respondents. Intraoperative hypoxemia and laryngeal injury were experienced by 75% and 51% of the respondents, respectively. The proportions of anesthesiologists who frequently experienced hypoxemia during OLV were 19%, 24%, and 7% for lung, cardiovascular, and esophageal surgeries, respectively. Up to 32% of respondents were reluctant to perform lung-protective ventilation strategies during OLV. Multiple regression analysis revealed that the volume-control ventilation mode and an SpO_2 intervention threshold of < 85% were independent risk factors for hypoxemia during OLV in lung and cardiovascular surgeries. In esophageal surgery, working in a tier 2 hospital and using traditional ventilation strategies were independent risk factors for hypoxemia during OLV. Subgroup analysis revealed no significant difference in intraoperative hypoxemia during OLV between respondents who performed lung-protective ventilation strategies and those who did not.

Conclusions Lung-protective ventilation strategies during OLV have been widely accepted in mainland China and are strongly recommended for esophageal surgery, particularly in tier 2 hospitals. Implementing volume control ventilation mode and early management of oxygen desaturation might prevent hypoxemia during OLV.

†Hong-jin Liu and Yong Lin contributed equally to this work.

*Correspondence:
Hui Zhang
xhzh@fjmu.edu.cn
Mei-fang Chen
13799400450@163.com
Full list of author information is available at the end of the article

Keywords One-lung ventilation, Lung protective ventilation, Hypoxemia, Postoperative pulmonary complications, Volume control ventilation

Background

One-lung ventilation (OLV), typically achieved by placing a double-lumen endotracheal tube (DLET) or bronchial blockers, plays a critical role in cardiothoracic surgery by providing optimal surgical exposure and protection of the nonoperated lung. Currently, lung protective ventilation strategies (LPVSs), characterized by low tidal volume, permissible hypercapnia, individualized positive end-expiratory pressure (PEEP), recruitment maneuvers, and low inspiratory oxygen concentrations, have become increasingly popular worldwide [1]. Studies have also reported that the perioperative application of LPVS can ameliorate ventilation-induced lung injury, reduce postoperative pulmonary complications (PPCs), and improve patient outcomes, especially in those at high risk for PPCs [2, 3]. However, no consensus or guidelines for LPVSs during OLV have been achieved. Ongoing debates persist regarding the benefit of the ventilation strategy and how to set the proper perioperative ventilation parameters [4].

Hypoxia is one of the most common complications during and after OLV, affecting 3.6–10.0% [5, 6] of patients undergoing OLV, and leads to cerebral dysfunction [7], myocardium ischemia [8], arrhythmia [9], and pulmonary hypertension [10]. In addition to inhibited hypoxic pulmonary vasoconstriction (HPV), hypoxia may be partially caused by airway problems, preexisting lung malfunction, and inappropriate ventilation strategies (high tidal volume, zero PEEP, etc.). Additional risk factors for intraoperative hypoxemia in cardiothoracic surgery include the side of surgery, surgical position, and the volume of the excised lung [6, 11].

This study aimed to explore the routine strategy for establishing and maintaining OLV in cardiothoracic surgery in China through a nationwide questionnaire survey and to identify the risk factors for intraoperative hypoxia during OLV in clinical practice using the lung isolation technique.

Methods

Study design

From October 2023 to December 2023, the WJS.cn survey platform (https://www.wjx.cn) was utilized to conduct this nationwide questionnaire survey about the practical experience in the LPVS of the OLV during cardiothoracic surgery. The survey included respondent demographics, the methods of OLV establishment, the intraoperative monitoring standards, and the complications associated with DLET intubation (see Additional file 1). All in-service anesthesiologists from mainland China were enrolled in this survey via the internet, which contained 30 questions propagated through WeChat (Tencent, Shenzhen, China) designed by the investigators. The answer sheets with (1) a repeat response from the same internet Protocol number, (2) less than 60 s of answer time, (3) incomplete answers, and (4) less than 1 year of anesthetic occupation experience were excluded from this survey.

Statistical methods

Data processing and analysis were performed using R version 4.3.0 (2023-04-21) and Zstats v 0.90 (www.medsta.cn/software). All statistical graphs were generated using Microsoft PowerPoint 2010 (Microsoft, USA) and GraphPad Prism 8.0.1 (GraphPad Software, USA). $P < 0.05$ was considered statistically significant. Respondent characteristics are presented as frequencies and percentages for categorical variables. The respondents were divided into two groups according to the incidence of intraoperative hypoxia: hypoxia occurred frequently, classified as high incidence, and never or occasionally occurred classified as low incidence), and univariate regression was performed. The multivariate logistic regression subsequently included the variables with a P value < 0.1. Finally, a subgroup analysis was performed using a forest plot to compare differences between the respondents who routinely received LVPS and those who received conventional ventilation in terms of the proportion of patients with high incidence rates of intraoperative hypoxia.

Results

General data presentation

A total of 600 questionnaires were distributed, 565 of which were successfully collected, including 543 valid responses (543/600, 90.5%) that covered all provincial administrative units in mainland China. Twenty-two responses were excluded from the study (see Figs. 1 and 2). More than two-thirds of the respondents held the title of chief physician, 86% of whom came from Tier 3 hospitals. The respondents' titles, gender, age, hospital location, hospital tiers, and years of experience in anesthesiology are presented in Fig. 3.

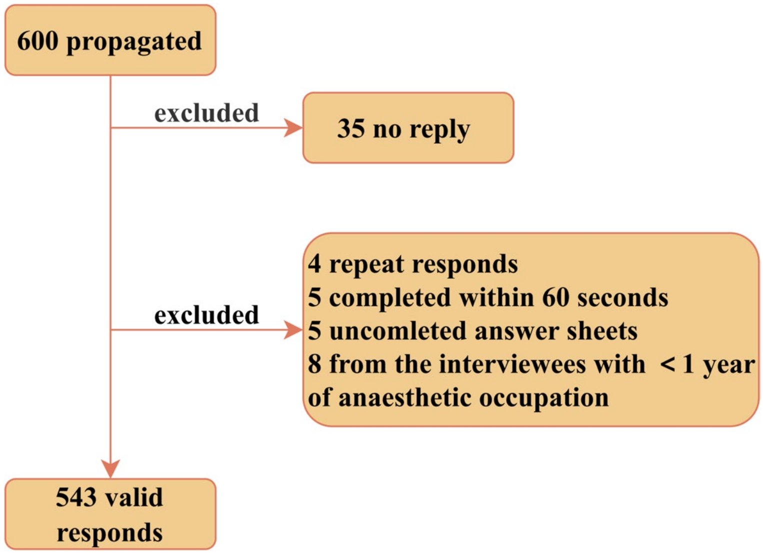

Fig. 1 Flow chart

One-lung ventilation establishment

Most respondents routinely evaluated respiratory function before surgery (see Fig. 4). The DLET and visual laryngoscope were commonly used to establish OLV (see Fig. 5A and B). The decision-making process for the sizes of artificial airways was based on body shape, sex, airway inner diameter, and surgical site for most of the respondents (see Fig. 5C). Bronchoscopy, visual DLET, and other visualization equipment were utilized for endotracheal placement in three-fourths of the respondents (see Fig. 5D). More than half of the respondents used pure oxygen preinhalation and traditional methods for lung collapse (see Fig. 5E).

Mechanical ventilation parameters

Up to 32% of respondents were reluctant to perform LPVS during OLV, with many citing concerns that LPVS was a complicated and impractical technique during cardiothoracic surgery (see Fig. 6). More than half of the respondents chose pure oxygen inspiration during OLV because of concerns about hypoxemia. Volume-controlled ventilation (VCV) mode, recruitment maneuvers, 4 to 6 mL per kilogram predictive body weight, pure oxygen inspiration, and a low-level PEEP of ≤ 5 cm H_2O were accepted by most respondents (see Fig. 7A, B, C, D and E). The most prevalent reason for performing pure oxygen inhalation during one-lung ventilation was concern about intraoperative hypoxemia (see Fig. 7F).

Intraoperative ventilation monitoring

The most common thresholds for intraoperative monitoring values were a peripheral oxygen saturation (SpO_2) of 90–94%, an end-tidal carbon dioxide ($ETCO_2$) of 45–55 mm Hg, and an airway pressure of 30–34 cm H_2O (see Fig. 8).

Perioperative complications

Hypoxemia was commonly observed during OLV surgery. The percentages of anesthesiologists who frequently experienced intraoperative hypoxemia were 19%, 24%, and 7% for lung, cardiovascular, and esophageal surgeries, respectively (see Fig. 9A). Hypoxemia and laryngeal injury were frequently experienced by 75% and 51% of the respondents, respectively (see Fig. 9B). Subgroup analysis revealed that no significant differences were observed between respondents who performed LPV during OLV and those who did not with respect to the high incidence of intraoperative hypoxemia (see Fig. 10).

Multiple regression analysis

The application of the VCV mode (OR: 0.54, 95% CI: 0.33–0.88, $P=0.014$) and an SpO_2 intervention threshold of < 85% (OR: 4.40, 95% CI: 1.12–17.36, $P=0.034$) were identified as independent risk factors for hypoxemia during OLV in lung surgery patients (see Additional file 2). The same risk factors were found for cardiovascular surgery (OR: 0.57, 95% CI: 0.34–0.94, $P=0.027$; OR: 5.29, 95% CI: 1.31–21.45, $P=0.020$) (see Additional file 3). In esophageal surgery, hospital tier and the traditional ventilation strategy were independent risk factors for postoperative hypoxemia after OLV (OR: 3.04, 95% CI: 1.32–6.97, $P=0.009$; OR: 3.04, 95% CI: 1.32–6.97, $P=0.009$) (see Additional file 4).

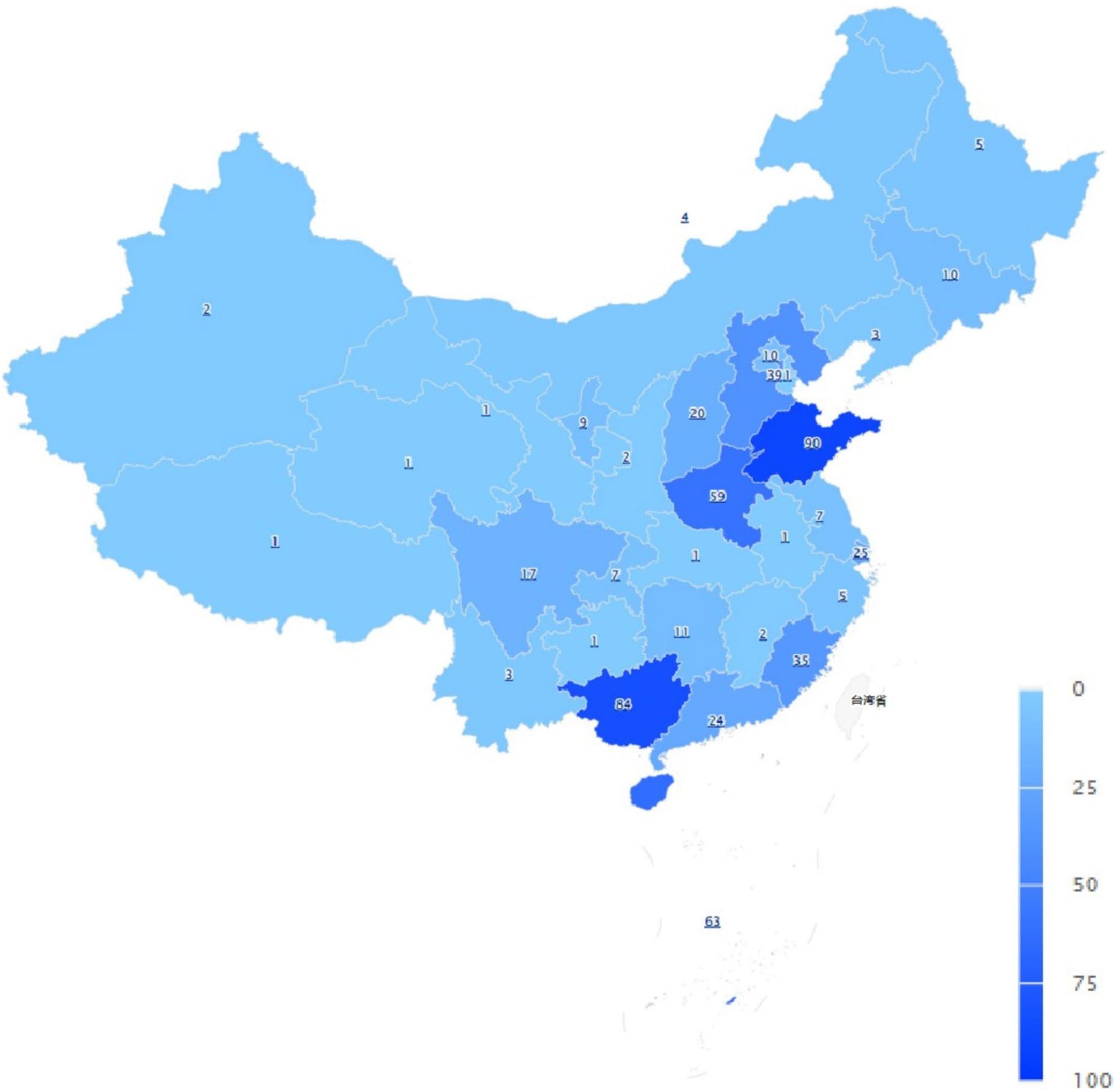

Fig. 2 Regional distribution of the respondents in mainland China

Discussion

Preoperative evaluation

Preoperative evaluation of respiratory function is crucial for preventing PPCs during cardiothoracic surgery. Chest computerized tomography clearly identifies preexisting pulmonary lesions and tracheal abnormalities [12, 13]. The need for lung function examination for patients scheduled for lobectomy is unassailable. The predicted postoperative forced expiratory volume in 1 s is the most effective index for predicting respiratory complications after thoracic surgery, while maximal oxygen uptake is the best predictor of postoperative prognosis [14]. A peak oxygen uptake of < 17 mL/(kg·min) and an anaerobic threshold of < 10.5 mL/(kg·min) were considered to be related to increased complications and a lower 5-year survival rate following esophageal surgery [15]. Arterial blood gas analysis can serve as a supplementary assessment for patients unable to undergo lung function examinations before thoracic surgery. While preoperative hypoxemia is a risk factor for postoperative complications, hypercapnia is not [16].

Establishment of lung isolation

Lung isolation is the core technique in anesthetic management during cardiothoracic surgery, in which DLET and bronchial blockers are frequently utilized

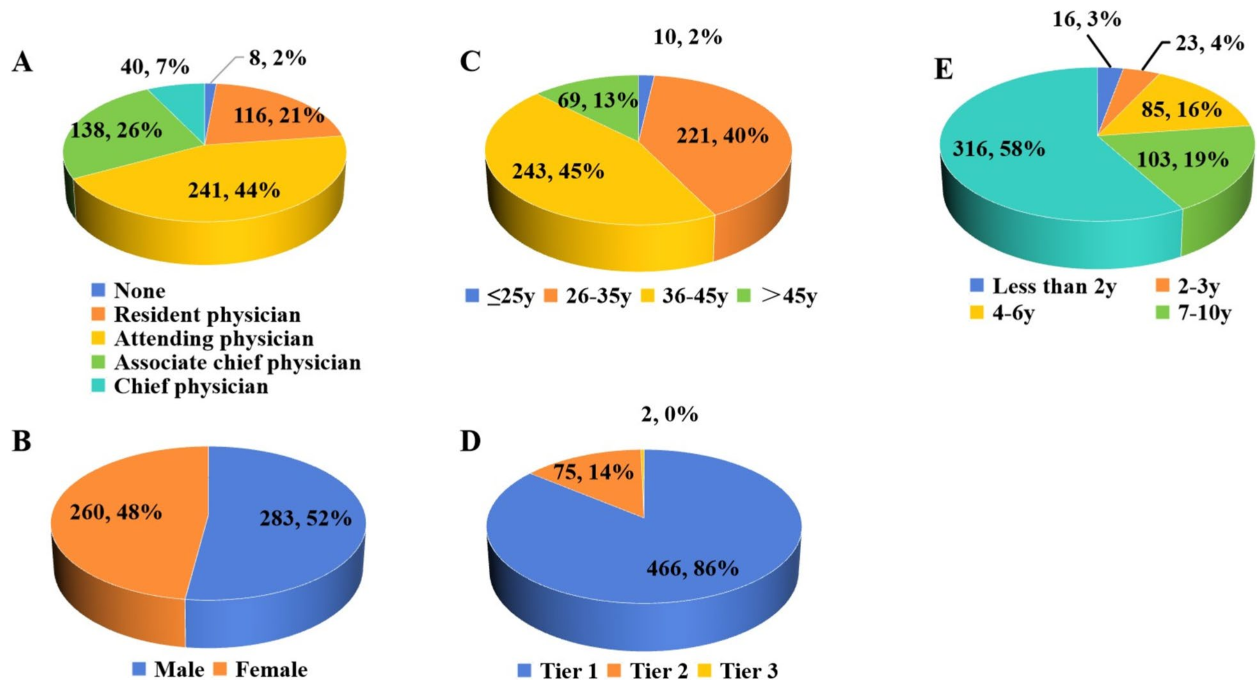

Fig. 3 General information of the respondents. **A** Titles of the respondents; **B** Gender of the respondents; **C** Age of the respondents. **D** Tiers of hospitals. **E** Duration in the field of anesthesiology

for establishing OLV [17]. No significant difference was found regarding the efficacy of intraoperative lung collapse between the two commonly used lung isolation techniques. However, DLET intubation seemed more time-saving in the bronchial location [18]. As a result, 94% of the respondents in the study reported using DLET. Successful lung isolation during surgery depends on precise endotracheal placement. It has been reported that chest auscultation contributes to 35% of malposition cases during bronchial intubation [19]. Therefore, fiberoptic bronchoscopy is considered the gold standard globally [20, 21]. However, some of the respondents (24%) relied on their clinical experiences, which may reflect a shortage of visual equipment in primary hospitals in mainland China.

Cardiothoracic surgery benefits from effective lung collapse, which consists of two stages. The lung rapidly deflates under the elastic force of the alveoli in the first stage, lasting less than one minute. As the small airway closes, the second stage begins, and the residual gas in the alveoli is slowly absorbed by the pulmonary capillary. Compared with the conventional manipulation of lung collapse, the open-clamp airway technique described by Rong Huang and colleagues was associated with more rapid and complete lung collapse and a lower incidence of hypoxemia during surgery [22]. A small-sample randomized controlled trial recently reported that preemptive OLV for lung collapse in thoracoscopic surgery was effective and safe [23]. However, conventional lung collapse manipulation was routinely performed by more than half of the respondents enrolled in this study, revealing that it was convenient and reliable for the majority of Chinese anesthesiologists under the stress of a heavy workload.

Lung protective ventilation strategy

The volume control ventilation mode, a tidal volume of 4 to 6 mL per predictive body weight (kg), pure oxygen inspiration, and a low-level PEEP of < 5 cm H_2O were the most acceptable ventilation parameters for the respondents in this study. Logistic regression analysis indicated that the VCV mode was an independent risk factor for intraoperative hypoxemia in pulmonary and cardiac surgery patients in this study. Compared with the volume control ventilation mode and the pressure control volume guarantee mode, lower airway pressure and higher dynamic lung compliance were monitored in patients in the pressure control ventilation mode. However, no significant difference was observed in the incidence of PPCs, indicating a weak relationship between airway pressure, dynamic lung compliance, and short-term respiratory outcomes after surgery [24, 25]. Moreover, patients at high risk of PPCs might benefit from the VCV mode, which is associated with lower volume and driving pressure [26]. Coincidentally, the majority of respondents

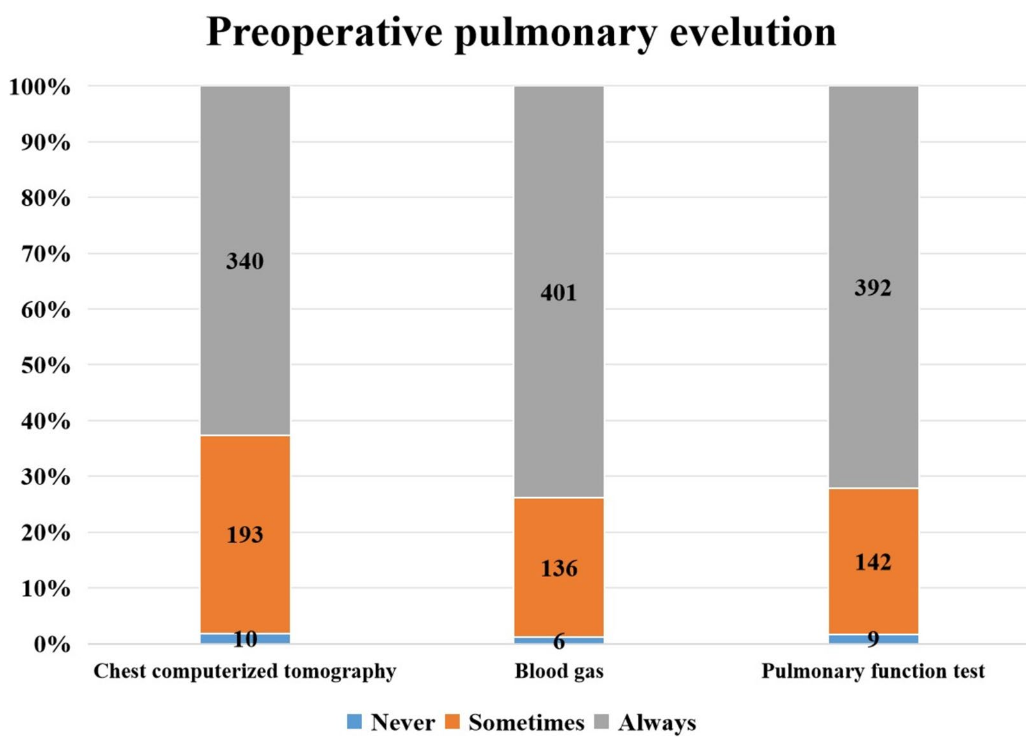

Fig. 4 Proportions of respondents whose respiratory function was evaluated at different frequencies

in this study routinely performed VCV during surgery. However, the authors could not confirm the reason why the VCV mode was prevalent in mainland China.

While low tidal volume ventilation is recommended for LPVSs, the incidence of PPCs does not decrease in patients without a proper level of PEEP during surgery [27]. Accordingly, most anesthesiologists in mainland China support this approach and utilize low tidal volume and low-level PEEP in their daily clinical practice. However, what we should note is that debates still exist

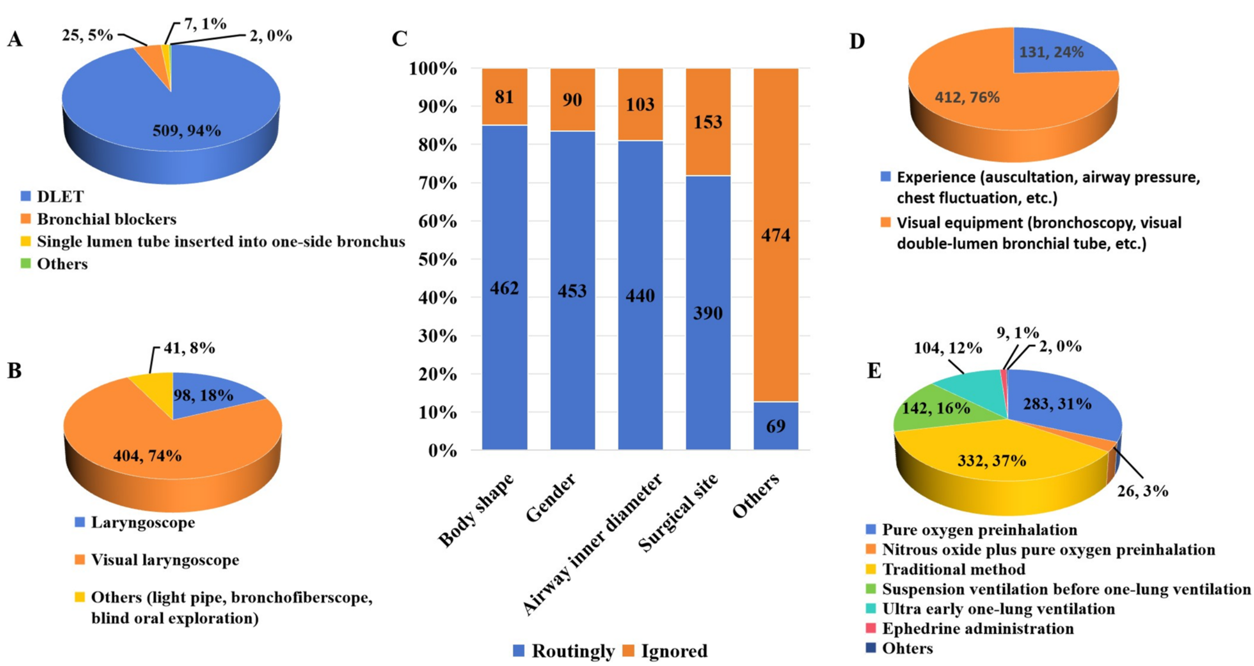

Fig. 5 The establishment of one-lung ventilation. **A** Lung isolation techniques; **B** Intubation tools; **C** Decision-making criteria for the sizes of artificial airways; **D** Intubation location; **E** Pulmonary collapse maneuvers

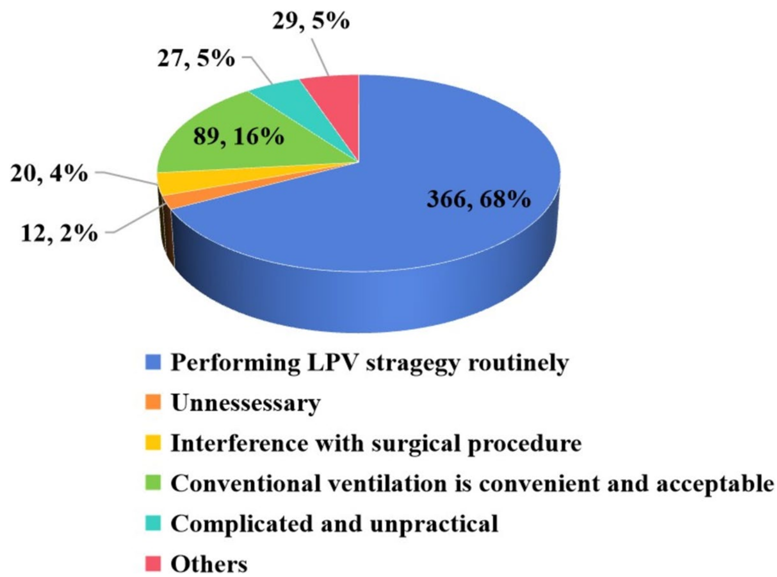

Fig. 6 Reasons why the lung protective ventilation strategies were not performed during one-lung ventilation

regarding whether low tidal volume ventilation combined with proper PEEP can reduce the number of PPCs in OLV [28].

High concentrations of inhaled oxygen can cause oxygen toxicity, resorption atelectasis, and other oxidative stress injuries and are closely associated with high incidences of PPCs and 30-day mortality [29, 30]. Nevertheless, 100% FiO_2 has been widely adopted in China. Not surprisingly, the main reason was the concern about intraoperative hypoxemia following OLV. The authors strongly recommend titrating the FiO_2 from a low level and keeping the FiO_2 as low as possible to maintain good oxygenation during OLV.

As previously mentioned, a proper PEEP setting plays an essential role in LPVS, preventing pulmonary atelectasis following long-term low tidal volume ventilation. However, no consensus has been reached concerning the standard PEEP level during OLV. A 5 cm H_2O PEEP setting failed to alleviate pulmonary inflammation and reduce serum biomarkers related to lung injury in patients who underwent OLV during esophagectomy [31]. In contrast, another observational study reported

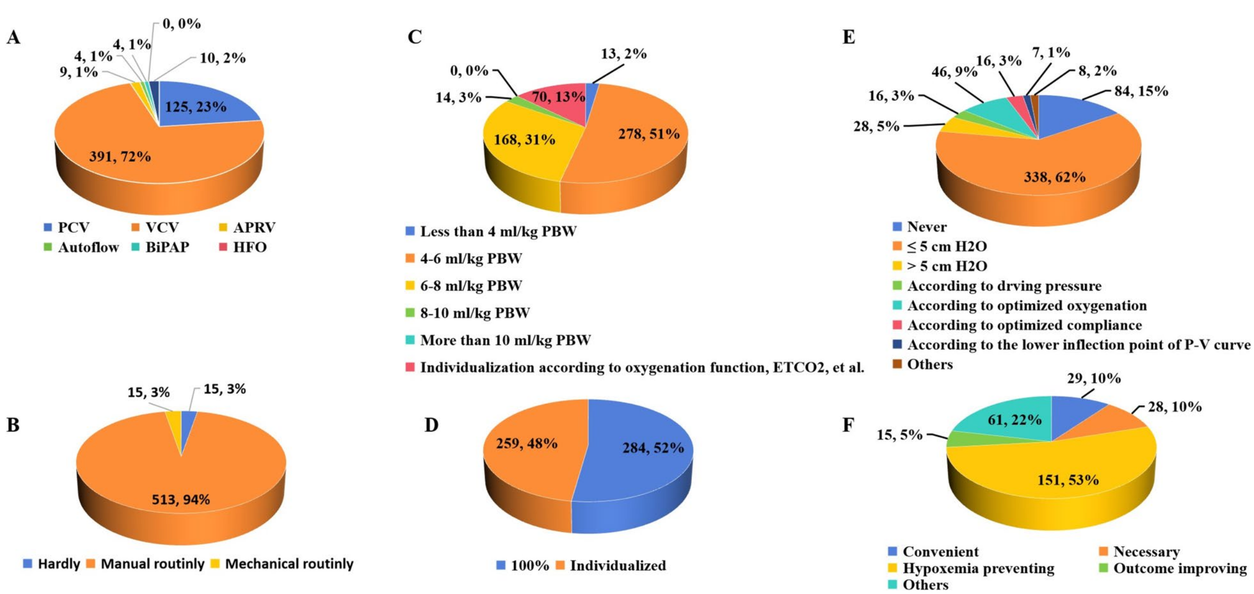

Fig. 7 Mechanical ventilation parameters. **A** Ventilation mode; **B** Lung recruitment maneuvers; **C** Initial tidal volume; **D** Initial FiO2; **E** Preferred positive end-expiratory pressure; **F** Reasons for pure oxygen inhalation during one-lung ventilation

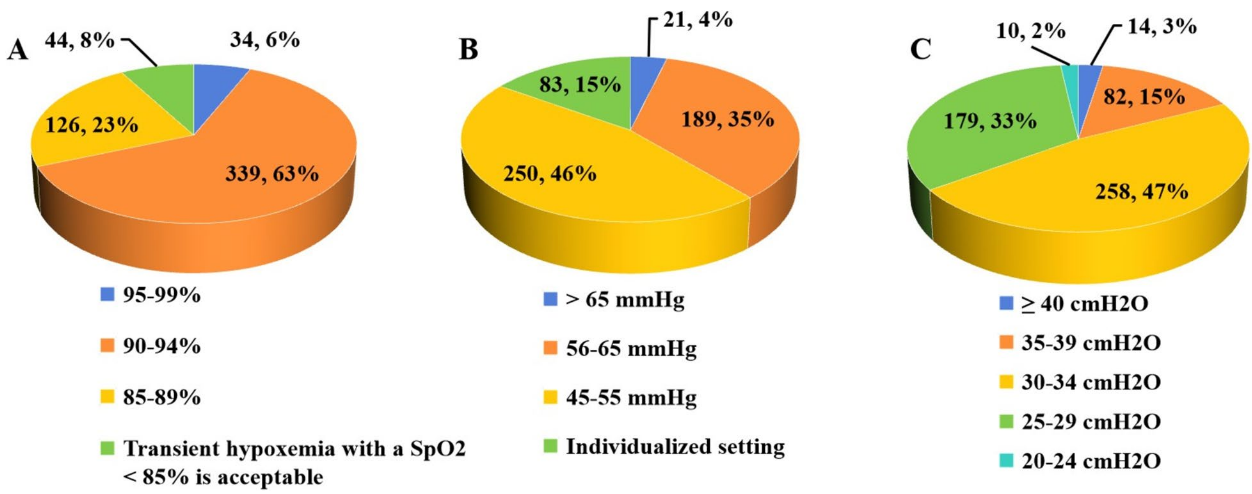

Fig. 8 Monitoring of intraoperative ventilation. **A** Lower threshold of SpO2; **B** Upper threshold of ETCO2; **C** Upper threshold of airway pressure

reduced PPCs at 5 cm H_2O PEEP compared with zero PEEP [30]. These findings demonstrated that patients experienced a lower incidence of pulmonary atelectasis and better lung compliance after driving pressure-guided ventilation with 8 cm H_2O PEEP in on-pump cardiac surgery [32]. Moreover, a multicenter randomized control trial confirmed the critical role of driving pressure in the PEEP setting, indicating its positive effect on intraoperative oxygenation function [33]. In general, a modified driving pressure of <16 cm H_2O was independently correlated with a lower incidence of PPCs, whereas VT <8 ml/kg and PEEP ≥ 5 cm H_2O were not associated with similar outcomes [34]. Hence, individualized PEEP settings according to the driving pressure level may be rational during OLV to optimize lung compliance and improve outcomes [35, 36]. Unfortunately, only a few respondents in this study performed PEEP titration during OLV, and the burdensome clinical task in mainland China and time constraints for driving pressure setting might explain the unsatisfactory results.

Alveolar recruitment maneuvers can prevent pulmonary atelectasis and improve oxygenation during general anesthesia [37]. Nearly all respondents in this study performed manual recruitment maneuvers during OLV. Notably, however, alveolar recruitment maneuvers have been associated with barotrauma, arrhythmia, re-expansion pulmonary edema, and recurrent atelectasis [38].

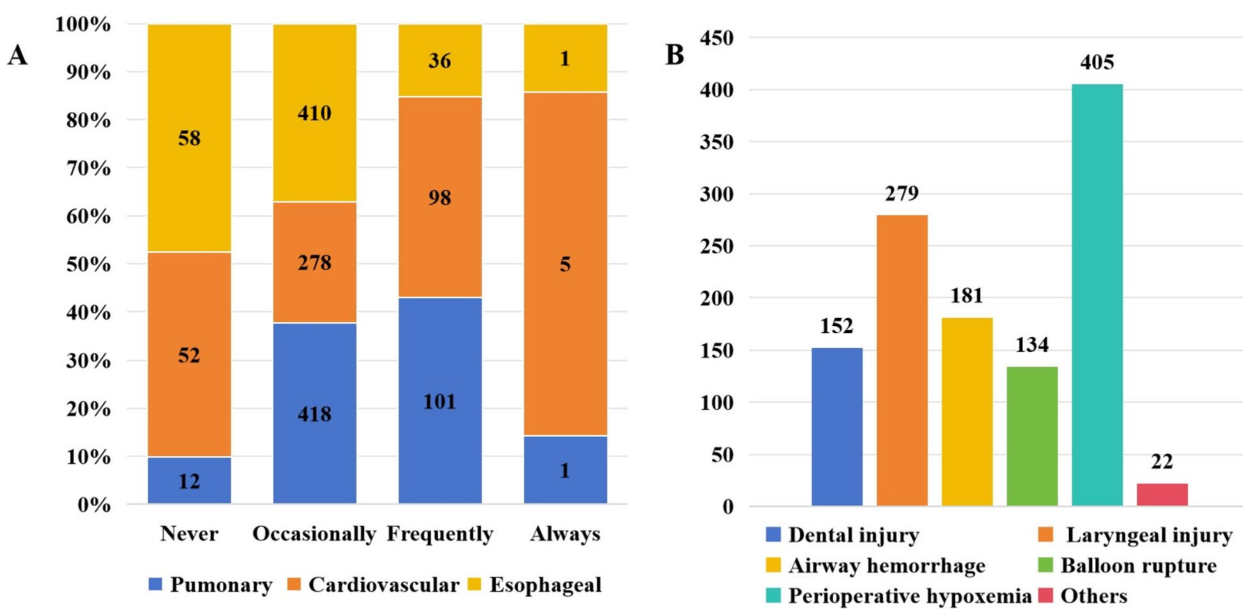

Fig. 9 Perioperative complications. **A** The proportions of respondents who experienced hypoxemia among different surgeries; **B** Complications frequently occurred after one-lung ventilation

Variables	n (%)	non-LPV	LPV	OR (95%CI)	P	P for interaction
		No. of events/ No. of total				
All interviewees	543 (100.00)	128/177	277/366	1.19 (0.79 ~ 1.79)	0.399	
Title						0.131
Resident physician	116 (21.36)	29/39	48/77	0.57 (0.24 ~ 1.34)	0.198	
Attending physician	241 (44.38)	54/80	119/161	1.36 (0.76 ~ 2.45)	0.298	
Associated chief physician	138 (25.41)	35/45	82/93	2.13 (0.83 ~ 5.47)	0.116	
Chief physician	40 (7.37)	8/10	27/30	2.25 (0.32 ~ 15.90)	0.416	
None	8 (1.47)	2/3	1/5	0.13 (0.00 ~ 3.22)	0.210	
Gender						0.422
Male	283 (52.12)	73/103	139/180	1.39 (0.80 ~ 2.41)	0.237	
Female	260 (47.88)	55/74	138/186	0.99 (0.54 ~ 1.84)	0.983	
Age						0.834
25 years or younger	10 (1.84)	2/4	2/6	0.50 (0.04 ~ 6.68)	0.600	
26-35 years	221 (40.70)	43/66	110/155	1.31 (0.71 ~ 2.42)	0.392	
36-45 years	243 (44.75)	66/85	125/158	1.09 (0.58 ~ 2.06)	0.790	
Older than 45 years	69 (12.71)	17/22	40/47	1.68 (0.47 ~ 6.05)	0.427	
Tiers of hospitals						0.783
Tier 3	466 (85.82)	100/142	243/324	1.26 (0.81 ~ 1.96)	0.303	
Tier 2 or Tier 1	77 (14.18)	28/35	34/42	1.06 (0.34 ~ 3.29)	0.916	
Duration in the field of anesthesiology						0.198
Less than 2 years	16 (2.95)	3/7	4/9	1.07 (0.15 ~ 7.82)	0.949	
2-3 years	23 (4.24)	10/11	7/12	0.14 (0.01 ~ 1.47)	0.102	
4-6 years	85 (15.65)	15/22	42/63	0.93 (0.33 ~ 2.64)	0.896	
7-10 years	103 (18.97)	18/32	52/71	2.13 (0.89 ~ 5.10)	0.090	
More than 10 years	316 (58.20)	82/105	172/211	1.24 (0.69 ~ 2.21)	0.471	
CT						0.906
Never or sometimes	203 (37.38)	48/66	105/137	1.23 (0.63 ~ 2.41)	0.545	
Always	340 (62.62)	80/111	172/229	1.17 (0.70 ~ 1.95)	0.549	
Blood gas						0.951
Never or sometimes	142 (26.15)	36/52	65/90	1.16 (0.55 ~ 2.44)	0.705	
Always	401 (73.85)	92/125	212/276	1.19 (0.73 ~ 1.93)	0.487	
Pulmonary evaluation						0.689
Never	9 (1.66)	2/3	4/6	1.00 (0.05 ~ 18.91)	1.000	
Sometimes	142 (26.15)	34/47	77/95	1.64 (0.72 ~ 3.71)	0.239	
Always	392 (72.19)	92/127	196/265	1.08 (0.67 ~ 1.74)	0.750	
Location						0.310
Judging by experience	131 (24.13)	37/51	66/80	1.78 (0.77 ~ 4.14)	0.178	
Judging by visual equipment	412 (75.87)	91/126	211/286	1.08 (0.68 ~ 1.73)	0.743	
Mode						0.453
Pressure control ventilation	125 (23.02)	43/53	57/72	0.88 (0.36 ~ 2.16)	0.786	
Volume control ventilation	391 (72.01)	82/120	206/271	1.47 (0.91 ~ 2.36)	0.113	
Others	27 (4.97)	3/4	14/23	0.52 (0.05 ~ 5.79)	0.594	
Tidal volume						0.268
Less than 4 ml/kg PBW	13 (2.39)	8/9	2/4	0.13 (0.01 ~ 2.18)	0.154	
4-6 ml/kg PBW	278 (51.20)	63/87	140/191	1.05 (0.59 ~ 1.85)	0.878	
6-8 ml/kg PBW	168 (30.94)	39/54	88/114	1.30 (0.62 ~ 2.73)	0.484	
8-10 ml/kg PBW	14 (2.58)	4/6	5/8	0.83 (0.09 ~ 7.68)	0.872	
Individualization	70 (12.89)	14/21	42/49	3.00 (0.89 ~ 10.06)	0.075	
FiO2						0.421
100%	284 (52.30)	78/104	136/180	1.03 (0.59 ~ 1.80)	0.917	
Individualization	259 (47.70)	50/73	141/186	1.44 (0.79 ~ 2.62)	0.230	
PEEP						0.346
Never	84 (15.47)	32/39	35/45	0.77 (0.26 ~ 2.25)	0.627	
Routinely	459 (84.53)	96/138	242/321	1.34 (0.86 ~ 2.09)	0.195	
SPO2						0.814
95-99%	34 (6.26)	7/12	13/22	1.03 (0.25 ~ 4.30)	0.966	
90-94%	339 (62.43)	73/103	182/236	1.39 (0.82 ~ 2.34)	0.222	
85-89%	126 (23.20)	36/48	57/78	0.90 (0.40 ~ 2.06)	0.812	
Transient lower than 85%	44 (8.10)	12/14	25/30	0.83 (0.14 ~ 4.93)	0.841	
ETCO2						0.396
More than 65 mm Hg	21 (3.87)	6/9	8/12	1.00 (0.16 ~ 6.25)	1.000	
56-65 mm Hg	189 (34.81)	42/59	102/130	1.47 (0.73 ~ 2.97)	0.278	
45-55 mm Hg	250 (46.04)	67/89	116/161	0.85 (0.47 ~ 1.53)	0.581	
Individualization	83 (15.29)	13/20	51/63	2.29 (0.75 ~ 6.97)	0.145	
Airway pressure						0.542
40 cm H2O or higher	14 (2.58)	4/5	5/9	0.31 (0.02 ~ 4.02)	0.372	
35-39 cm H2O	82 (15.10)	26/34	33/48	0.68 (0.25 ~ 1.84)	0.445	
30-34 cm H2O	258 (47.51)	64/90	129/168	1.34 (0.75 ~ 2.40)	0.318	
25-29 cm H2O	179 (32.97)	32/45	104/134	1.41 (0.66 ~ 3.02)	0.378	
20-24 cm H2O	10 (1.84)	2/3	6/7	3.00 (0.12 ~ 73.64)	0.501	
Recruitment						0.846
Hardly	15 (2.76)	4/5	7/10	0.58 (0.04 ~ 7.66)	0.682	
Manual routinely	513 (94.48)	118/165	263/348	1.23 (0.81 ~ 1.87)	0.326	
Mechanical routinely	15 (2.76)	6/7	7/8	1.17 (0.06 ~ 22.94)	0.919	
PEEP setting rules during one-lung ventilation						0.358
Never	84 (15.47)	32/39	35/45	0.77 (0.26 ~ 2.25)	0.627	
More than 5 cm H2O	338 (62.25)	70/103	181/235	1.58 (0.95 ~ 2.64)	0.081	
Driving pressure	28 (5.16)	7/8	15/20	0.43 (0.04 ~ 4.39)	0.475	
Optimized oxygenation	16 (2.95)	3/4	6/12	0.33 (0.03 ~ 4.19)	0.395	
Optimized compliance	46 (8.47)	9/12	23/34	0.70 (0.16 ~ 3.10)	0.635	
P-V curve	31 (5.71)	7/11	17/20	3.24 (0.57 ~ 18.38)	0.185	

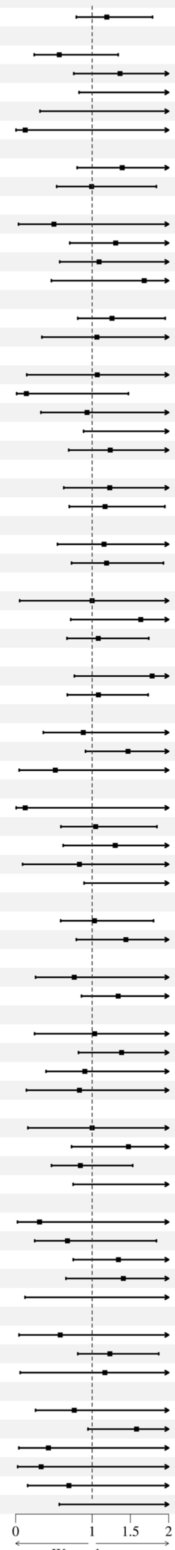

Fig. 10 Subgroup analysis for the risk factors for hypoxemia during one-lung ventilation. A forest plot was constructed to compare differences between respondents who routinely received lung-protective ventilation strategies and those who received conventional ventilation strategies in terms of the incidence of intraoperative hypoxia

Permissive hypercapnia represents a fundamental component of LPVSs and was adopted as part of the ventilation strategy by the majority of respondents in this study. First, hypercapnia may potentiate HPV, augmenting blood flow to the ventilated lung and improving ventilationperfusion (V/Q) matching. Second, mild hypercapnia may stimulate the sympathetic nervous system, leading to increased cardiac output. Specifically, 35% of the respondents permitted ETCO2 levels between 56 and 65 mmHg during OLV, whereas 46% adhered to a more conservative strategy, maintaining the intervention threshold within the range of 45–55 mmHg. A recent prospective, randomized controlled trial suggested that the intraoperative target arterial carbon dioxide tensions of 50 ± 5 mm Hg and 60 ± 5 mm Hg significantly improved pulmonary oxygenation during OLV compared with 40 ± 5 mmHg, without a higher incidence of PPCs or prolongation of hospital stay [39].

Moreover, up to 32% of respondents did not accept LPVS during OLV, and most regarded LPVS as a complicated and impractical ventilation strategy. Colquhoun, DA, and colleagues reported no obvious difference in outcomes as the application of LPVS increased [28], indicating that the individualization ventilation strategy was more rational for OLV during cardiothoracic surgery.

Airway pressure during one-lung ventilation

Barotrauma serves as a pivotal mechanism contributing to ventilator-induced lung injury [40]. Evidence from numerous studies suggests that lower driving pressures are linked to a decreased incidence of PPCs [30]. In contrast, elevated driving pressure contributes to lung injury during positive-pressure ventilation [41]. Hence, airway pressure should be maintained below 30 cm H_2O, which is associated with a reduced risk of death in patients with acute lung injury [42]. In patients with compromised pulmonary function, it is recommended that peak airway pressures remain under 20 to 25 cm H_2O [43]. Moreover, elevated airway pressure may reduce preload and increase afterload to the right ventricle, leading to hypoxemia and hemodynamic disturbance [44]. Notably, high airway pressure during OLV usually indicates malposition or obstruction of the DLET [45]. Unfortunately, the authors found that up to 65% of respondents did not check the airway unless the airway pressure rose to ≥ 30 cm H_2O during OLV, indicating a prevalence of undervaluation of abnormal airway pressure during surgery. Given the serious adverse outcomes, high airway pressure should not be ignored and must be addressed immediately.

Hypoxemia during one-lung ventilation

Hypoxemia, characterized by a SpO_2 of less than 90% or partial pressure of oxygen/fraction of inspired oxygen (PaO_2/FiO_2) of less than 40 KPa (300 mm Hg) [46, 47], frequently occurs during OLV [6]. With advances in lung isolation techniques and anesthetics, intraoperative hypoxemia has decreased significantly [6, 48]. However, 74.6% of the respondents in this study reported episodes of transient hypoxemia during OLV, and 5.0–23.0% of them frequently experienced intraoperative hypoxemia, suggesting that hypoxemia during OLV is still common and warrants more attention in cardiothoracic surgery in China.

No consensus has been reached on the optimal intervention threshold for hypoxemia during OLV. Transient mild hypoxemia (SpO_2 of 85–90%) may be acceptable, followed by elevated cardiac output and hemoglobin levels [49]. However, a dose-dependent relationship has been reported between intraoperative hypoxemia ($SpO_2 < 90\%$ for more than 2 min) and postoperative delirium [50]. Given that elderly patients with multiple comorbidities may have impaired tolerance to hypoxemia, maintaining $SpO_2 \geq 90\%$ during OLV is generally recommended. In this study, a SpO_2 of 90% or higher was accepted by 69% of interviewers, and 23% did not address hypoxemia until the SpO_2 decreased from 85 to 89%. Moreover, a transient SpO_2 of less than 85% was permitted in 8% of the respondents. Logistic regression analysis revealed that a threshold of $SpO_2 < 85\%$ was an independent risk factor for intraoperative hypoxemia during pulmonary and cardiovascular surgeries, which may be explained by several factors: (1) As the relationship between PaO_2 and arterial oxygen saturation is not linear, pulse oximetry cannot provide immediate warning of hypoxemia [51, 52]. (2) SpO_2 values lower than 85% during surgery indicate several critical situations requiring urgent management, such as DLET malposition [45], airway obstruction with sputum, or severe V/Q rate mismatches due to increased nonventilated perfusion [6]. (3) Compared with other thoracic surgeries, cardiopulmonary dysfunction often occurs in lung and cardiovascular surgeries. Accordingly, frequent hypoxemia was reported in 19% of respondents during OLV in pulmonary surgery and by 24% in cardiovascular surgery in our study. In contrast, only 7% of respondents frequently reported hypoxemia during OLV in esophageal surgery, suggesting that OLV impaired oxygenation function in cardiopulmonary surgery.

Logistic regression analysis identified tier 2 hospitals and conventional ventilation strategies as independent risk factors for hypoxemia during OLV in esophageal surgery patients. The relatively high incidence of intraoperative hypoxemia in tier 2 hospitals may be attributable to staffing shortcomings, inadequate mechanical facilities, lower professional levels, and suboptimal anesthetic strategies. Michelet and colleagues demonstrated that the LPV strategy can mitigate the systemic proinflammatory response in patients undergoing esophagectomy, improve the PaO_2/FiO_2 ratio, and shorten the duration of postoperative mechanical ventilation [53]. Furthermore, the duration of OLV has been verified as a risk factor for PPCs in esophageal surgery, emphasizing the importance of minimizing OLV duration and using LPV strategies [54]. Based on these findings, LPV is strongly recommended to reduce the incidence of hypoxemia and improve patient outcomes after esophageal surgery.

Although LPVS is considered critical in the protective effect on the lungs, the risk analysis revealed a negative result in preventing intraoperative hypoxemia during OLV. The authors propose two primary reasons for the paradoxical results. First, the LPVS protocol was not performed completely by the respondents enrolled in this survey. The discrepancy between the "recognized LPVS" and their "self-perceived LPVS" should not be ignored. Specifically, more convincing evidence is needed to support the current concept of LPVSs, and consensus or guidelines with respect to LPVSs during OLV are still lacking. Second, patients at low risk for PPCs after thoracic surgery may not benefit from LPVS [55]. The mechanical power, first described in 2016, might be another novel key factor for PPCs and reflects the energy transmitted from the ventilator to the lung [56].

There were several limitations in this study. First, the data from the questionnaire-based survey were completely subjective, which might introduce bias into the findings. Second, owing to constraints on the response time, the questionnaire did not include more detailed information, such as short-term and long-term postoperative outcomes. Finally, the number of valid responses varied markedly among the provinces around China, potentially limiting its ability to accurately represent the current status of clinical practice in OLV.

Conclusions

As the second most populous country in the world, mainland China had only 92,726 anesthesiologists, or 6 to 7 anesthesiologists per 100,000 people in 2018. From 2015 to 2017, the workload of anesthesiologists in China increased by 10% [57]. Owing to their busy clinical workload, Chinese anesthesiologists often accept convenient ventilation strategies during OLV in cardiothoracic surgery. DLET intubation is usually applied to establish lung isolation. The majority of respondents perform low tidal volume, VCV mode, regular low-level PEEP, and manual recruitment maneuvers routinely during OLV. These findings indicate that the VCV mode during OLV may be associated with a reduced incidence of intraoperative hypoxemia in cardiothoracic surgery patients. A low SpO_2 threshold of less than 85% during OLV may contribute to adverse outcomes, suggesting the need for early intervention in patients with oxygen desaturation during surgery. As the conventional ventilation strategy might be an independent risk factor for hypoxemia during OLV in esophageal surgery, LPV is routinely performed in esophageal surgery.

Abbreviations

OLV	One lung ventilation
DLET	Double-lumen endotracheal tube
LPVS	Lung protective ventilation strategies
PEEP	Positive end-expiratory pressure
PPCs	Postoperative pulmonary complications
HPV	Hypoxic pulmonary vasoconstriction
VCV	Volume control ventilation
SpO_2	Saturation of peripheral oxygen
$ETCO_2$	End-tidal carbon dioxide

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12871-024-02879-x.

Additional file 1.

Additional file 2.

Additional file 3.

Additional file 4.

Acknowledgements

The authors are grateful to the reviewers and editor for their help and suggestions. The authors also thank Jian Huang, Cheng-hui Zhou, Hai-ling Wang, Zhong-rong Fang, peng-yu Qin, Lan Lan, Cong-jie Bi, Ying Chen, Xiao-ning Zhu, Liang Zhang, Nan Wang, Yi-ting Huang, Tao Sun, Yu-guang Bai, Hong-mei Ma, Shao-sheng Wu and all the other colleagues in the medical community who participated in the study.

Authors' contributions

Hong-jin Liu and Yong LIN: Writing-original draft preparation and conceptualisation. Xiao-hui Guo, Ning-ning Chen, Jie-chao Tan, Yi-na He, Si-si Chen, Yan Mu: Data curation and visualisation. Wang Li and Xian-wen Liu: Investigation. Hai Yang and Pei-lei Guo: Methodology and Supervision. Wen-yue Kang: Software, Validation. Mei-fang CHEN and Hui Zhang: Supervision, writing, reviewing, and editing. All authors read and approved the final manuscript.

Funding

This project is funded by the Natural Science Foundation of Fujian Province (2021J01769) and Joint Funds for the Innovation of Science Innovation of Science and Technology, Fujian Province (2020Y9019).

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee of Fujian Medical University Union Hospital, and all participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Cardiovascular Surgery, Fujian Medical University Union Hospital, Xinquan Road 29, Fuzhou, Fujian 350001, PR China. [2]Department of Physical Examination Center, Fujian Medical University Union Hospital, Xinquan Road 29, Fuzhou, Fujian 350001, PR China. [3]Department of Critical Care Medicine, Fujian Medical University Union Hospital, Xinquan Road 29, Fuzhou, Fujian 350001, PR China. [4]Department of Anesthesiology, Shandong Provincial Hospital Affiliated with Shandong First Medical University, Jinan, China. [5]Department of Anesthesiology, The First People's Hospital of Yulin,

Yulin, China. [6]Department of Anesthesiology, Hainan General Hospital, Hainan Affiliated Hospital of Hainan Medical University, Haikou, China. [7]Department of Anesthesiology, The Fifth Affiliated Hospital of Zhengzhou University, Zhengzhou, China. [8]Department of Anesthesia and Surgery, The Third People's Hospital of Henan Province, Zhengzhou, China. [9]Department of Anesthesiology, Binzhou People's Hospital, Binzhou, China. [10]Department of Anesthesiology, Shunde Hospital of South Medical University, Foshan, China. [11]Department of Anesthesiology, Nanchong Hospital of Beijing Anzhen Hospital Capital Medical University, Sichuan, Nanchong, China. [12]Department of Anesthesiology, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou, China. [13]Department of Anesthesiology, The Second Central Hospital of Baoding, Baoding, China. [14]Department of Anesthesiology, Liaocheng People's Hospital, Liaocheng, China.

Received: 25 October 2024 Accepted: 25 December 2024
Published online: 07 January 2025

References

1. Young CC, Harris EM, Vacchiano C, et al. Lung-protective ventilation for the surgical patient: international expert panel-based consensus recommendations. Br J Anaesth. 2019;123(6):898–913. https://doi.org/10.1016/j.bja.2019.08.017.
2. Serpa Neto A, Cardoso SO, Manetta JA, et al. Association between use of lung-protective ventilation with lower tidal volumes and clinical outcomes among patients without acute respiratory distress syndrome: a meta-analysis. JAMA. 2012;308(16):1651–9.https://doi.org/10.1001/jama.2012.13730.
3. Serpa Neto A, Hemmes SN, Barbas CS, et al. Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis. Lancet Respir Med. 2014;2(12):1007–15. https://doi.org/10.1016/S2213-2600(14)70228-0.
4. Hu XY, Du B. Lung-protective ventilation during one-lung ventilation: known knowns, and known unknowns. J Thorac Disease. 2019;11(Suppl 3):S237-40. https://doi.org/10.21037/jtd.2019.01.45.
5. Wang W, Gong Z, Zhao M, et al. Hypoxemia in thoracoscopic lung resection surgery using a video double-lumen tube versus a conventional double-lumen tube: a propensity score-matched analysis. Front Surg. 2023;10:1090233. https://doi.org/10.3389/fsurg.2023.1090233.
6. Karzai W, Schwarzkopf K. Hypoxemia during one-lung ventilation: prediction, prevention, and treatment. Anesthesiology. 2009;110(6):1402–11. https://doi.org/10.1097/ALN0b013e31819fb15d.
7. Snyder B, Simone SM, Giovannetti T, Floyd TF. Cerebral hypoxia: its role in age-related chronic and acute cognitive dysfunction. Anesth Analg. 2021;132(6):1502–13. https://doi.org/10.1213/ane0000000000005525.
8. Liu P, Chen J, Qi J, et al. Hesperetin ameliorates ischemia/hypoxia-induced myocardium injury via inhibition of oxidative stress, apoptosis, and regulation of ca(2+) homeostasis. Phytother Res. 2023;37(5):1787–805. https://doi.org/10.1002/ptr.7693.
9. Varney JA, Dong VS, Tsao T, et al. COVID-19 and arrhythmia: an overview. J Cardiol. 2022;79(4):468–75. https://doi.org/10.1016/j.jjcc.2021.11.019.
10. El Alam S, Pena E, Aguilera D, Siques P, Brito J. Inflammation in pulmonary hypertension and edema induced by hypobaric hypoxia exposure. Int J Mol Sci. 2022;23(20):12656. https://doi.org/10.3390/ijms232012656.
11. Hu B, Zhou H, Zou X. Placement of a double-lumen endotracheal tube. N Engl J Med. 2021;385(27):2591–2. https://doi.org/10.1056/NEJMc2117870.
12. Smith BM, Traboulsi H, Austin JHM, et al. Human airway branch variation and chronic obstructive pulmonary disease. Proc Natl Acad Sci U S A. 2018;115(5):E974-981. https://doi.org/10.1073/pnas.1715564115.
13. Beder S, Kupeli E, Karnak D, Kayacan O. Tracheobronchial variations in Turkish population. Clin Anat. 2008;21(6):531–8. https://doi.org/10.1002/ca.20667.
14. Lederman D, Easwar J, Feldman J, Shapiro V. Anesthetic considerations for lung resection: preoperative assessment, intraoperative challenges and postoperative analgesia. Ann Transl Med. 2019;7(15):356. https://doi.org/10.21037/atm.2019.03.67.
15. Santos BF, Souza HC, Miranda AP, Cipriano FG, Gastaldi AC. Performance in the 6-minute walk test and postoperative pulmonary complications in pulmonary surgery: an observational study. Braz J Phys Ther. 2016;20(1):66–72. https://doi.org/10.1590/bjpt-rbf.2014.0119.
16. Turner SE, Eastwood PR, Cecins NM, Hillman DR, Jenkins SC. Physiologic responses to incremental and self-paced exercise in COPD: a comparison of three tests. Chest. 2004;126(3):766–73. https://doi.org/10.1378/chest.126.3.766.
17. Somma J, Couture ÉJ, Pelletier S, et al. Non-ventilated lung deflation during one-lung ventilation with a double-lumen endotracheal tube: a randomized-controlled trial of occluding the non-ventilated endobronchial lumen before pleural opening. Can J Anaesth. 2021;68(6):801–11. https://doi.org/10.1007/s12630-021-01957-9.
18. Shum S, Moreno Garijo J, Tomlinson G, et al. A clinical comparison of 2 bronchial blockers Versus double-Lumen tubes for one-lung ventilation. J Cardiothorac Vasc Anesth. 2023;37(12):2577–83. https://doi.org/10.1053/jjvca202308125.
19. Klein U, Karzai W, Bloos F, et al. Role of fiberoptic bronchoscopy in conjunction with the use of double-lumen tubes for thoracic anesthesia: a prospective study. Anesthesiology. 1998;88(2):346–50. https://doi.org/10.1097/00000542-199802000-00012.
20. Cohen E. Double-lumen tube position should be confirmed by fiberoptic bronchoscopy. Curr Opin Anaesthesiol. 2004;17(1):1–6. https://doi.org/10.1097/00001503-200402000-00002.
21. Varma S, Beardow Z, Elliot SC, Mallick A. Intraoperative bronchoscopy prevents hypoxaemia during one-lung ventilation for second-stage oesophagectomy: a prospective cohort study. Eur J Anaesthesiol. 2010;27(10):919–21. https://doi.org/10.1097/EJA.0b013e3283387cad.
22. Huang R, Wang N, Lin X, et al. Facilitating lung collapse for thoracoscopic surgery utilizing endobronchial airway occlusion preceded by Pleurotomy and one-minute suspension of two-lung ventilation. J Cardiothorac Vasc Anesth. 2023. https://doi.org/10.1053/j.jvca.2023.11.007.
23. Zhang Y, Yan W, Fan Z, et al. Preemptive one lung ventilation enhances lung collapse during thoracoscopic surgery: a randomized controlled trial. Thorac Cancer. 2019;10(6):1448–52. https://doi.org/10.1111/1759-771413091.
24. Li XF, Jin L, Yang JM, et al. Effect of ventilation mode on postoperative pulmonary complications following lung resection surgery: a randomised controlled trial. Anaesthesia. 2022;77(11):1219–27. https://doi.org/10.1111/anae15848.
25. Kim KN, Kim DW, Jeong MA, Sin YH, Lee SK. Comparison of pressure-controlled ventilation with volume-controlled ventilation during one-lung ventilation: a systematic review and meta-analysis. BMC Anesthesiol. 2016;16(1):72. https://doi.org/10.1186/s12871-016-0238-6.
26. Bagchi A, Rudolph MI, Ng PY, et al. The association of postoperative pulmonary complications in 109,360 patients with pressure-controlled or volume-controlled ventilation. Anaesthesia. 2017;72(11):1334–43. https://doi.org/10.1111/anae14039.
27. Blank RS, Colquhoun DA, Durieux ME, et al. Management of one-lung ventilation: impact of tidal volume on complications after thoracic surgery. Anesthesiology. 2016;124(6):1286–95. https://doi.org/10.1097/ALN0000000000001100.
28. Colquhoun DA, Leis AM, Shanks AM, et al. A Lower Tidal volume regimen during one-lung ventilation for lung resection surgery is not Associated with reduced postoperative pulmonary complications. Anesthesiology. 2021;134(4):562–76. https://doi.org/10.1097/ALN.0000000000003729.
29. Edmark L, Auner U, Lindback J, Enlund M, Hedenstierna G. Post-operative atelectasis - a randomised trial investigating a ventilatory strategy and low oxygen fraction during recovery. Acta Anaesthesiol Scand. 2014;58(6):681–8. https://doi.org/10.1111/aas12322.
30. Ladha K, Vidal Melo MF, McLean DJ, et al. Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: hospital based registry study. BMJ. 2015;351:h3646. https://doi.org/10.1136/bmjh3646.
31. van der Woude MC, Bormans L, van der Horst RP, et al. Pulmonary levels of biomarkers for inflammation and lung injury in protective versus conventional one-lung ventilation for oesophagectomy: a randomised clinical trial. Eur J Anaesthesiol. 2020;37(11):1040–9. https://doi.org/10.1097/EJA0000000000001126.
32. Li XF, Jiang RJ, Mao WJ, et al. The effect of driving pressure-guided versus conventional mechanical ventilation strategy on pulmonary complications following on-pump cardiac surgery: a randomized clinical trial. J Clin Anesth. 2023;89: 111150. https://doi.org/10.1016/j.jclinane.2023.111150.
33. Park M, Yoon S, Nam JS, et al. Driving pressure-guided ventilation and postoperative pulmonary complications in thoracic surgery: a

multicentre randomised clinical trial. Br J Anaesth. 2023;130(1):e106-118. https://doi.org/10.1016/j.bja.2022.06.037.
34. Mathis MR, Duggal NM, Likosky DS, et al. Intraoperative mechanical ventilation and postoperative pulmonary complications after cardiac surgery. Anesthesiology. 2019;131(5):1046–62. https://doi.org/10.1097/ALN0000000000002909.
35. Ferrando C, Carraminana A, Pineiro P, et al. Individualised, perioperative open-lung ventilation strategy during one-lung ventilation (iPROVE-OLV): a multicentre, randomised, controlled clinical trial. Lancet Respir Med. 2024;12(3):195–206. https://doi.org/10.1016/S2213-2600(23)00346-6.
36. Park M, Ahn HJ, Kim JA, et al. Driving pressure during thoracic surgery: a randomized clinical trial. Anesthesiology. 2019;130(3):385–93. https://doi.org/10.1097/ALN.0000000000002600.
37. Hartland BL, Newell TJ, Damico N. Alveolar recruitment maneuvers under general anesthesia: a systematic review of the literature. Respir Care. 2015;60(4):609–20. https://doi.org/10.4187/respcare.03488.
38. Ball L, Hemmes SNT, Serpa Neto A, et al. Intraoperative ventilation settings and their associations with postoperative pulmonary complications in obese patients. Br J Anaesth. 2018;121(4):899–908. https://doi.org/10.1016/j.bja.2018.04.021.
39. Joe YE, Lee CY, Kim N, et al. Effect of permissive hypercarbia on lung oxygenation during one-lung ventilation and postoperative pulmonary complications in patients undergoing thoracic surgery: a prospective randomised controlled trial. Eur J Anaesthesiol. 2023;40(9):691–8. https://doi.org/10.1097/EJA0000000000001873.
40. Telias I, Brochard LJ, Gattarello S, et al. The physiological underpinnings of life-saving respiratory support. Intensive Care Med. 2022;48(10):1274–86. https://doi.org/10.1007/s00134-022-06749-3.
41. Neto AS, Hemmes SN, Barbas CS, et al. Association between driving pressure and development of postoperative pulmonary complications in patients undergoing mechanical ventilation for general anaesthesia: a meta-analysis of individual patient data. Lancet Respir Med. 2016;4(4):272–80. https://doi.org/10.1016/S2213-2600(16)00057-6.
42. Goligher EC, Ferguson ND, Brochard LJ. Clinical challenges in mechanical ventilation. Lancet (London England). 2016;387(10030):1856–66. https://doi.org/10.1016/s0140-6736(16)30176-3.
43. Schultz MJ, Haitsma JJ, Slutsky AS, Gajic O. What tidal volumes should be used in patients without acute lung injury? Anesthesiology. 2007;106(6):1226–31. https://doi.org/10.1097/01.anes.0000267607.25011.e8.
44. Jozwiak M, Teboul JL. Heart-lungs interactions: the basics and clinical implications. Ann Intensiv Care. 2024;14(1):122. https://doi.org/10.1186/s13613-024-01356-5.
45. Campos JH, Hallam EA, Van Natta T, Kernstine KH. Devices for lung isolation used by anesthesiologists with limited thoracic experience: comparison of double-lumen endotracheal tube, Univent torque control blocker, and Arndt wire-guided endobronchial blocker. Anesthesiology. 2006;104(2):261–6. https://doi.org/10.1097/00000542-200602000-00010.
46. Teng C, Fei Z, Liu H, Liu X, Hu Z. Effect of pre-operative hypoxemia on the occurrence and outcomes of post-operative ARDS in Stanford type a aortic dissection patients. Respir Res. 2023;24(1):161. https://doi.org/10.1186/s12931-023-02457-8.
47. Dong SA, Guo Y, Liu SS, et al. A randomized, controlled clinical trial comparing remimazolam to propofol when combined with alfentanil for sedation during ERCP procedures. J Clin Anesth. 2023;86: 111077. https://doi.org/10.1016/j.jclinane.2023.111077.
48. Ishikawa S, Lohser J. One-lung ventilation and arterial oxygenation. Curr Opin Anaesthesiol. 2011;24(1):24–31. https://doi.org/10.1097/ACO0b013e3283415659.
49. Durkin C, Romano K, Egan S, Lohser J. Hypoxemia during one-lung ventilation: does it really matter? Curr Anesthesiol Rep. 2021;11(4):414–20. https://doi.org/10.1007/s40140-021-00470-5.
50. Ahrens E, Tartler TM, Suleiman A, et al. Dose-dependent relationship between intra-procedural hypoxaemia or hypocapnia and postoperative delirium in older patients. Br J Anaesth. 2023;130(2):e298-306. https://doi.org/10.1016/j.bja.2022.08.032.
51. Applegate RL 2, Dorotta IL, Wells B, Juma D, Applegate PM. The relationship between Oxygen Reserve Index and arterial partial pressure of Oxygen during surgery. Anesth Analg. 2016;123(3):626–33. https://doi.org/10.1213/ane.0000000000001262.
52. Fleming NW, Singh A, Lee L, Applegate RL. 2nd: Oxygen Reserve Index: utility as an early warning for desaturation in high-risk surgical patients. Anesth Analg. 2021;132(3):770–6. https://doi.org/10.1213/ane0000000000005109.
53. Michelet P, D'Journo XB, Roch A, et al. Protective ventilation influences systemic inflammation after esophagectomy: a randomized controlled study. Anesthesiology. 2006;105(5):911–9. https://doi.org/10.1097/00000542-200611000-00011.
54. Lai G, Guo N, Jiang Y, et al. Duration of one-lung ventilation as a risk factor for postoperative pulmonary complications after McKeown esophagectomy. Tumori. 2020;106(1):47–54. https://doi.org/10.1177/0300891619900805.
55. El-Khatib M, Zeeni C, Shebbo FM, et al. Intraoperative mechanical power and postoperative pulmonary complications in low-risk surgical patients: a prospective observational cohort study. BMC Anesthesiol. 2024;24(1):82. https://doi.org/10.1186/s12871-024-02449-1.
56. Gattinoni L, Tonetti T, Cressoni M, et al. Ventilator-related causes of lung injury: the mechanical power. Intensive Care Med. 2016;42(10):1567–75. https://doi.org/10.1007/s00134-016-4505-2.
57. Zhang C, Wang S, Li H, et al. Anaesthesiology in China: a cross-sectional survey of the current status of anaesthesiology departments. Lancet Reg Health Western Pac. 2021;12:100166. https://doi.org/10.1016/j.lanwpc.2021.100166.

Publisher's Note