Heliyon 9 (2023) e15737

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

# The anesthesia management of totally thoracoscopic cardiac surgery: A single-center retrospective study

Hang Tian [a,1], Yan-jun Chen [b,1], He Tian [b], Xiao-shen Zhang [c], Hua Lu [c], Si Shen [d,**], Hao Wang [b,*]

[a] Department of Anesthesiology, Guangzhou Women and Children's Medical Center, Guangdong Provincial Clinical Research Center for Child Health, Guangzhou, 510623, PR China
[b] Department of Anesthesiology, The First Affiliated Hospital, Jinan University, Guangzhou 510630, PR China
[c] Department of Cardiovascular Surgery, The First Affiliated Hospital, Jinan University, Guangzhou 510630, PR China
[d] Department of Radiology, The First Affiliated Hospital, Jinan University, Guangzhou 510630, PR China

ARTICLE INFO

*Keywords:*
Totally thoracoscopic cardiac surgery
Anesthesia management
Perioperative complications
Length of stay

ABSTRACT

Anesthesia management of Totally thoracoscopic cardiac surgery (TTCS) has been the subject of much debate and discussion. In this single center retrospective study, we summarize the experience of clinical anesthesia management for TTCS by review the medical records of our medical center and look forward to its future development. In this retrospective study, 103 patients (49 male and 54 female) were enrolled, the mean age was 56.7 ± 14.4 years old. The participants underwent Mitral Valve Replacement (MVR) + Tricuspid Valve Annuloplasty (TVA) (42, 40.8%), Mitral Valve Annuloplasty (MVA) + TVA (38, 36.9%), MVA (21, 20.4%), and MVR (2, 1.9%) , respectively. Intraoperative hypoxemia, radiographic pulmonary infiltrates, and pneumonia were observed in 19 (18.4%), 84 (81.6%), and 13 (12.6%) patients, respectively. The LOS of ICU and POD were as follows: MVR + TVA (55.1 ± 25h, 9.9 ± 3.5 d), MVA + TVA (56.5 ± 28.4h, 9.4 ± 4.2d), MVA (37.9 ± 21.9h, 8.1 ± 2.3d) and MVR (48 ± 4.2h, 7.5 ± 2.1d). No reintubation, reoperations, postoperative cognitive dysfunction, 30-day mortality were observed in the present study. The present study demonstrated that applying this anesthesia management for TTCS associated with acceptable morbidity, intensive care unit and postoperative hospital lengths of stay. The finding from the present study might provide some new approach for Anesthesia management of TTCS.

## 1. Introduction

In recent years, totally thoracoscopic cardiac surgery (TTCS) has been used for coronary artery bypass grafting, resection of cardiac myxoma [1], valve replacement [2], atrial septal defect (ASD) and ventricular septal defect (VSD) closure [3,4] (Fig. 1). Studies have found that TTCS has significant advantages over full classical sternotomy in terms of small surgical trauma, shorter patient stay, shorter

* Corresponding author. Department of Anesthesiology, the First Affiliated Hospital, Jinan University, No. 613, West Huangpu Avenue, Tianhe District, Guangzhou 510630, PR China.
** Corresponding author. Department of Radiology, the First Affiliated Hospital, Jinan University, No. 613, West Huangpu Avenue, Tianhe District, Guangzhou 510630, PR China.
*E-mail addresses:* cecilyshen@126.com (S. Shen), haowang@jnu.edu.cn (H. Wang).
[1] Equal contributors: Hang Tian and Yan-jun Chen contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2023.e15737
Received 9 February 2023; Received in revised form 18 April 2023; Accepted 20 April 2023
Available online 23 April 2023

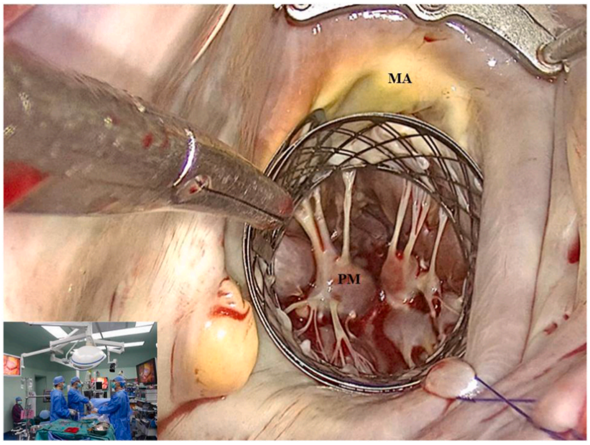


**Fig. 1.** Totally thoracoscopic mitral Valve Annuloplasty procedure. MA, Mitral annulus; PM, Papillary muscles.

**Table 1**
Baseline characteristics and demographics of patients underwent totally thoracoscopic Cardiac Surgery.

| Variables | TTCS (n = 103) |
|---|---|
| Age (years) | 56.7 ± 14.4 |
| Gender | |
| Male | 49 (47.6%) |
| Female | 54 (52.4%) |
| Smock | 12 (11.7%) |
| Drink | 3 (2.9%) |
| NYHA class | |
| I/II | 68 (66.0%) |
| III/IV | 35 (34.0%) |
| Pulmonary hypertension | 29 (28.2%) |
| Coronary artery heart disease | 13 (12.6%) |
| Hypertension | 15 (14.7%) |
| Atrial fibrillation | 32 (31.1%) |
| Diabetes mellitus | 8 (7.8%) |
| Chronic kidney disease | 2 (1.9%) |
| Heart failure | 3 (2.9%) |
| COPD | 1 (0.9%) |
| Cerebral Infarction | 6 (5.8%) |
| Asthma | 1 (0.9%) |
| Previous pneumonia | 7 (6.8%) |

Continuous data are reported as mean (SD); categorical data are presented as number (%).NYHA , New York Heart Association; COPD , chronic obstructive pulmonary disease.

recovery duration, less acute and chronic pain, improved scar cosmetic outcomes, faster return to normal activities without compromising the safety of the surgery [5], and improved hospital bed turnover [4]. The emergence and development of TTCS has greatly promoted the progress of cardiac surgery and is considered a major technological milestone in cardiac surgery. At the same time, anesthesia management in TTCS is becoming increasingly delicate and complex, posing new challenges to anesthesiologists. In this article, we summarize the experience of clinical anesthesia management for TTCS by reviewing the medical records of our medical center from 2020 to 2022.

## 2. Results

During the study period, 103 patients underwent elective TTCS, all of whom underwent elective surgery; the baseline characteristics and demographics are shown in Table 1. The mean age was 56.7 ± 14.4 years old and 49 (47.6%) patients were male. Notably, according to the New York Heart Association (NYHA) grade, 68 (66%) patients belonged to class I or II. The three most common concomitant disorders were atrial fibrillation 32 (31.1%), pulmonary hypertension (29, 28.2%), and hypertension 15 (14.7%).

The 4 procedures performed in the enrolled patients were Mitral Valve Replacement (MVR) + Tricuspid Valve Annuloplasty (TVA) (42,40.8%), Mitral Valve Annuloplasty (MVA) + TVA (38, 36.9%), MVA (21, 20.4%), and MVR (2, 1.9%). Outcomes related to surgery, such as surgical time, CPB and aortic cross-clamping time, ventilatory support time, and LOS in the ICU and POD are presented in

**Table 2**
In-hospital outcomes of totally thoracoscopic Cardiac Surgery.

| Variables | MVR (n = 2) | MVA (n = 21) | MVR + TVA (n = 42) | MVA + TVA (n = 38) |
|---|---|---|---|---|
| Surgery time (min) | 241.5 ± 23.3 | 216.8 ± 48.0 | 266.9 ± 63.5 | 260.5 ± 61.1 |
| CPB time (min) | 150.5 ± 20.5 | 132.9 ± 27.4 | 152.9 ± 31.2 | 157.1 ± 34.5 |
| Cross-clamp time (min) | 90 ± 18.4 | 72.6 ± 18.0 | 90 ± 25.7 | 88 ± 25.7 |
| Ventilatory support (hours) | 11.5 ± 8.5 | 10.9 ± 8.5 | 12 ± 7.3 | 15.2 ± 6.7 |
| LOS in ICU (hours) | 48 ± 4.2 | 37.9 ± 21.9 | 55.1 ± 25 | 56.5 ± 28.4 |
| LOS on POD (days) | 7.5 ± 2.1 | 8.1 ± 2.3 | 9.9 ± 3.5 | 9.4 ± 4.2 |

Continuous data are reported as mean (±SD); categorical data are presented as number (%).MVR, Mitral Valve Replacement; MVA, Mitral Valve Annuloplasty; TVA, Tricuspid Valve Annuloplasty; CPB, Cardiopulmonary bypass; LOS, length of stay; POD, postoperative day.

**Table 3**
Perioperative complications of totally thoracoscopic Cardiac Surgery.

| Variables | TTCS (n = 103) |
|---|---|
| Intraoperative complications | |
| Hypoxemia | 19 (18.4%) |
| rSO2 decreasing | 103 (100%) |
| Postoperative complications | |
| Hypoxemia | 3 (2.9%) |
| Bilateral lung infiltrates | 38 (36.9%) |
| Right lung infiltrates | 43 (41.7%) |
| Left lung infiltrates | 3 (2.91%) |
| Pneumonia | 13 (12.6%) |
| Postoperative pain | 13 (12.6%) |
| Incision infection | 3 (2.91%) |
| Postoperative cognitive dysfunction | 0 (0%) |
| Reintubation | 0 (0%) |
| Reoperation | 0 (0%) |
| 30-day mortality | 0 (0%) |
| Chronic pain | 0 (0%) |
| Consumption of Morphine (mg) | |
| The first day after TTCS | 23.6 ± 8.7 |
| The first 3day after TTCS | 40.5 ± 5.6 |

Categorical data are presented as number (%).TTCS , totally thoracoscopic Cardiac Surgery; rSO2 , regional cerebral oxygen saturation.

Table 2.

Perioperative complications are presented in Table 3. Documented intraoperative hypoxemia occurred in 19 (18.4%) patients and was corrected immediately after manual hyperinflation and "1.5-lung ventilation". 13 patients complained of postoperative pain and received rescue morphine (23.6 ± 8.7 mg for the first days after TTCS, and 40.5 ± 5.6 mg for the first 3 days after TTCS). It is worth noting that although only 13 (12.6%) patients developed pneumonia, postoperative CXR showed that 84 (81.6%) patients had some degree of radiographic pulmonary infiltrates, among which, bilateral lung, right lung, and left lung infiltrates accounted for 38 (36.9%), 43 (41.7%), and 3 (2.91%), respectively. No reintubation, reoperations, postoperative cognitive dysfunction, 30-day mortality, or chronic pain were observed in the present study.

## 3. Discussion

Since the introduction of minimally invasive cardiac surgery (MICS) in 1990s [6,7], as a main MICS procedure, TTCS has become the current trend in cardiac surgery [8,9]. In our center, TTCS has been used for MVR/MVA, TVR/TVA, resection of atrial myxoma, repair of atrial septal or ventricular septal defects, and radiofrequency ablation of atrial fibrillation. In this retrospective study, we summarized the TTCS anesthesia management experience and provided some novel findings by reviewing TTCS cases at our center over the past 22 months.

Respiratory management is the key point of TTCS anesthesia, affected by combined respiratory disease, OLV, and CPB, and patients have a high risk of perioperative hypoxemia and hypercapnia [10–13]. Therefore, we took a series of measures to prevent and correct perioperative hypoxemia and hypercapnia, including pre-operative respiratory muscle endurance training (RMET) [14–17], pre-operative intramuscular injection of Penehyclidine Hydrochlorideby [18], sufficient sputum suction. In this study, when patients developed hypoxemia, we also innovatively used "1.5-lung ventilation" in addition to manual hyperinflation, but this should be done after full communication with the cardiac surgeon, as this procedure may affect the surgical field to some extent. The results showed that intraoperative hypoxemia was rapidly corrected in our patients after the above procedures, and only one patient developed transient hypoxemia after extubation.

Recent studies have shown that TTCS may cause a significant decrease in regional cerebral oxygen saturation (rSO2) [19], and this decline is associated with cognitive dysfunction [20], cerebral tissue hypoxemia, and higher mortality [21]. In our center, $rSO_2$ was routinely monitored during TTCS, consistent with other current studies [19,22] We also found that the patient's $rSO_2$ decreased significantly during surgery, but none of the patients developed POCD or other new brain complications. Although studies have shown that the decrease in $rSO_2$ seems to be more closely related to CPB and surgical procedures [22], whether it is related to OLV warrants further study.

OLV is an iatrogenic risk factor for developing perioperative acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) [23]. ARDS was reported in 7.9% of patients after pneumonectomy and 2.9% after lobectomy, with mortality rates of 50% and 42% [24]. For the early detection of postoperative pulmonary complications, CXR was routinely performed in our center, despite little evidence to support this practice. The results showed that 81.6% of patients had some degree of radiographic pulmonary infiltrates; most interestingly, it seems that the isolated lungs had a higher risk of radiographic pulmonary infiltrates than the ventilated lung, which deserves further study.

Because of incisions, sternotomy, intercostal nerve damage, chest retraction, vein graft harvesting, operative position, invasion of chest tubes, endotracheal tube, etc. [25], cardiac surgery is associated with significant post-operative pain. Poorly controlled PP has been shown to increase the risk of pulmonary, cardiovascular, and endocrine complications, long LOS, and chronic pain [26]. Beyond suffering, pain affects post-operative rehabilitation, resulting in functional disability that prevents return to normal work and life [27]. Considering that high-dose opioid therapy is associated with prolonged intubation and ventilator-associated pneumonia, which may lead to a longer ICU stay and higher mortality [28], we adopted a multimodal analgesia strategy with SAPB as the main intervention. Several high-quality randomized controlled trials have found that SAPB allows better pain management and reduces the use of rescue analgesia [29,30]. In this study, we reviewed patients' VAS scores and consumption of rescue morphine on the first and third day after surgery, respectively, the results showed that there were 13 patients complained of moderate pain (VAS:4–6) and received rescue morphine. Telephone follow-up results showed that none of the returning patients in this study reported chronic pain.

Since the introduction of fast-track cardiac anesthesia (FTCA) in the 1990s [31], it has been controversial whether FTCS really benefits patients. Some studies believe that taking FTCS results in a decreased postoperative ventilation time and a reduced use of costs and resources [32,33], but others suggest that FTCS does not reduce the length of ICU stay [33] and that the FTCS protocol may pose challenges for post-operative respiratory status and pain management [34]. In our center, we did not deliberately adopt FTCS strategies; therefore, the postoperative ventilation time was longer than that of FTCS.

TTCS is a complex medical technology with a longer learning curve [35], both surgeons and anesthesiologists have some influence on the surgical procedure and outcome, which may have affected the results. To exclude this bias, all participants in this retrospective study were from the same surgical and anesthesia team. The results showed that although the CPB and cross-clamp times were relatively longer, the LOS in the ICU and POD were significantly shorter compared to the data from another study [9].

The present study has some limitations. First, this is a single-center study involving only a small group of patients, and long-term post-operative safety and efficacy require multicenter studies with large sample sizes and longer studies. Second, in this study, the age range of our included patients was 18–75 years old, with an average age of 56.7 $\pm$ 14.4. The patients were relatively young, further research is needed in older or younger patients. Finally, this Retrospective study lacked a control group to compare the perioperative outcomes.

## 4. Conclusions

In conclusion, the present study demonstrated that applying this anesthesia management for TTCS was feasible, and associated with low incidence of perioperative complications and acceptable intensive care unit and postoperative hospital lengths of stay. The finding from the present study might provide some new approach for Anesthesia management of TTCS.

## 5. Materials and methods

### *5.1. Design and setting*

In the present retrospective study, we collected data from patients who underwent elective TTCS during 22-month period from January 2021 to October 2022 at The First Affiliated Hospital of Jinan University. All operations were performed or supervised by the same one surgeon and one anesthesiologist. Ethical approval for this study (JNUKY-2021-045) was provided by IRB of Jinan University, CHINA on December 13, 2021. Because this was a retrospective study, informed consent was not obtained from participants.

### *5.2. Inclusion and exclusion criteria*

In this study, both of the following 2 selection criteria must be met: (1) patient underwent elective valve surgery via totally thoracoscopic, and (2) patient older than 18 years and younger than 75 years old. Exclusion criteria are any one of the following: (1) history of lung disease, right-sided chest operation; (2) ejection fraction $<$30%, hypertension $\geq$180 mmHg; (3) pulmonary arterial systolic pressure of 60 mmHg or greater; (4)patients who are lost to follow-up.

### *5.3. Statistical analysis*

SPSS version 20.0 software was used for statistical analysis. Continuous variables are presented as mean $\pm$ SD, whereas categorical

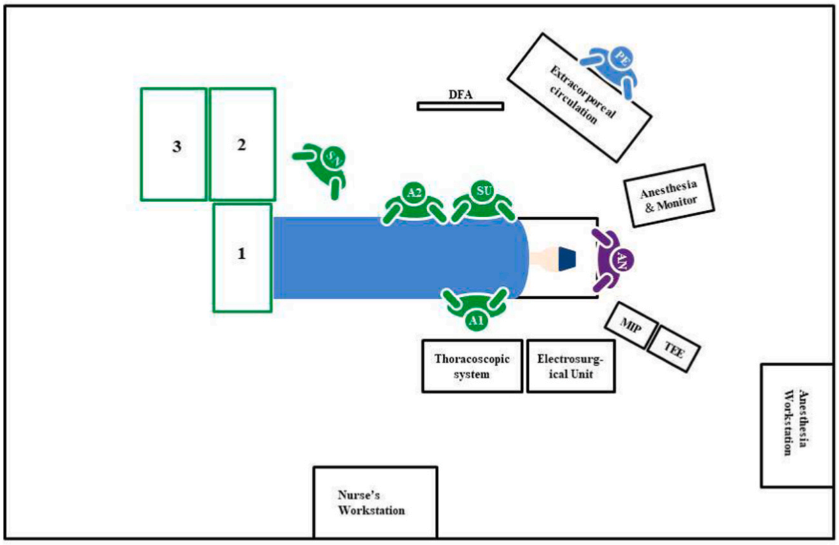


**Fig. 2.** Schematic representation of the operating room layout for totally thoracoscopic Cardiac Surgery. AN, Anesthesiologist; SU, Surgeon; SN, Scrub nurse; A1, A2, 1st and 2nd assistant; PE, Perfusionist; MIP, Multichannel infusion pump; TEE, Transesophageal echocardiography; DFA, display for 1st assistant.

variables are presented as absolute numbers, percentages of total, or both.

## 6. Anesthesia management

### *6.1. Pre-operative management*

- Pre-anesthesia assessment: Similar to classical full sternotomy cardiac surgery, our pre-anesthesia evaluation also focused on assessing left and right ventricular function through disease history and preoperative examination. However, TTCS requires one-lung ventilation (OLV) before and after Cardiopulmonary bypass (CPB), during which hypoxemia is prone to occur; therefore, pulmonary function tests related to respiratory function were routinely performed in all patients before surgery.
- Extensive pre-operative counseling: Before the operation, extensive counseling and education were provided to all the participants on anesthesia techniques, possible clinical outcomes, potential complications, and postoperative self-care measures. We encouraged patients to quit smoking and alcohol consumption 2 weeks before surgery (at least one week, except for emergency surgery).
- pre-operative respiratory muscle endurance training (RMET): Patients undergoing cardiac surgery are at risk of pulmonary complications, which leads to increased intra- and post-operative morbidity and mortality. Because of CPB [36] and OLV [37], patients who undergo TTCS are more likely to develop perioperative pulmonary complications. Currently, studies have shown that pre-operative respiratory training can reduce pulmonary complications and shorten the LOS for POD [14,16,17]. All patients at our heart center underwent evaluation of maximum inspiratory pressure (MIP) via an analog manometer and initiated inspiratory muscle training with a pressure linear load device (Threshold® Respironics® IMT), with 40% of the MIP, performing 3 sets with 10 repetitions, this training was performed twice a day until the day before TTCS.
- Specialized pre-anesthetic medication: Specialized pre-anesthetic medication for TTCS increases patient satisfaction and may also provide numerous safety benefits. At our center, calcium channel blockers, β-blockers, digitalis, angiotension converting enzyme inhibitor (ACEI), and antiarrhythmic drugs that patients are taking before surgery continue to be used until the day of surgery. All patients received morphine (0.1 mg $kg^{-1}$, IM) to sedate the patient and relieve the burden on the heart, and Penehyclidine Hydrochlorideby (0.5–1 mg, IM) to improve perioperative oxygenation index and reduce lung ischemia-reperfusion injury.

### *6.2. Intra-operative management*

- Layout of TTCS operating room (OR): The OR design and surgical department layout have an essential impact on the surgical team's collaboration and communication, intraoperative processes, and overall efficiency of the surgical procedures [38]. Considering that the TTCS requires more equipment and tables, we had specially replanned the OR layout, as shown in Fig. 2.
- Intraoperative monitoring: All patients were monitored using continuous five-lead ECG and peripheral saturation. The invasive arterial blood pressure (IBP), central venous pressure (CVP), bispectral index (BIS), and regional cerebral oxygen saturation (rSO2) were obtained every minute. Real-time transesophageal echocardiography (TEE) was routinely performed to reduce cardiovascular complications (Fig. 3). We did not routinely monitor pulmonary artery pressure unless there was a clear indication.

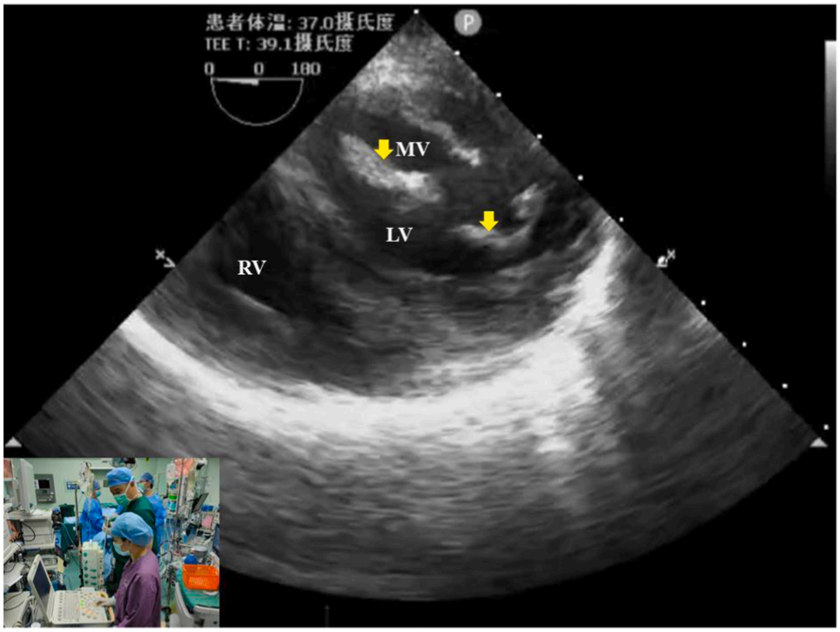


**Fig. 3.** Intraoperative transesophageal echocardiography. LV, Left ventricle; RV, Right ventricle; MV，Mitral valve.


**Fig. 4.** Fibreoptic bronchoscopy guided left-double lumen endotracheal intubation.

- Left-double lumen endotracheal intubation: During TTCS, airway management is generally achieved with lung isolation using left-double lumen endotracheal intubation or single-lumen tubes with bronchial blockers [39,40]. At our center, all patients underwent video laryngoscopy and fiberoptic bronchoscopy guided left double-lumen endotracheal intubation to obtain adequate exposure and visualization during TTCS (Fig. 4). The left double lumen endotracheal tube was replaced with a single lumen and safely transferred to the ICU with a transport ventilator as soon as TTCS was completed.
- Ultrasound-guided serratus anterior plane block (SAPB): A linear ultrasound (US) probe (13–16 MHz) was placed over the mid-clavicular region of the thoracic cage in a sagittal plane to identify the fifth rib, latissimus dorsi, and major and serratus anterior muscles [41]. Once the serratus anterior plane was confirmed, the block was performed with a 70 mm long, 20 gauge, short bevel needle, and 30 ml of 0.33% ropivacaine was injected after negative aspiration of blood (Fig. 5). In-plane technology was used for all patients.

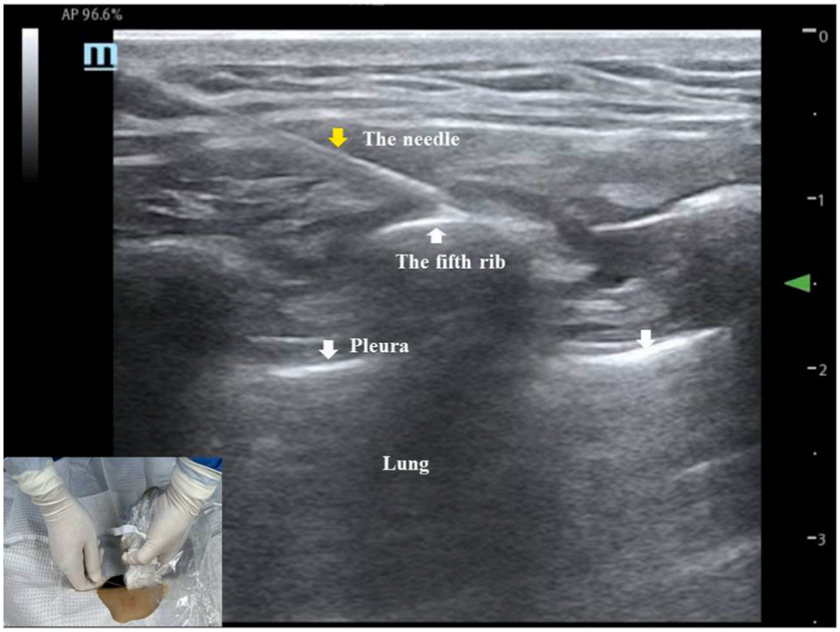


**Fig. 5.** Ultrasound guided Serratus anterior block procedure.

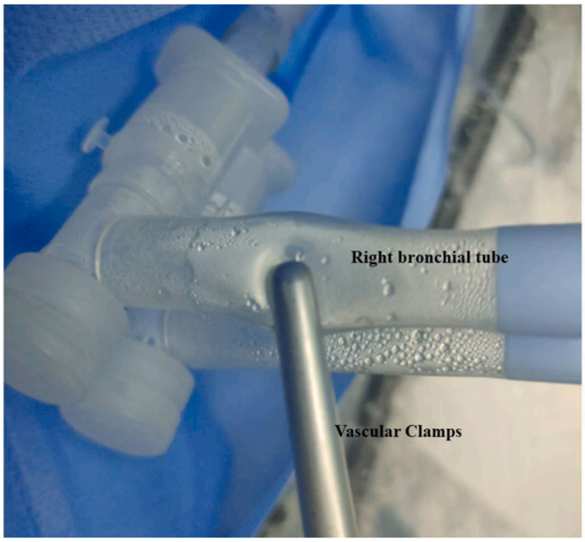


**Fig. 6.** When intraoperative persistent hypoxemia occurs, 1/2 of the right bronchial tube was clamped with Vascular Clamps.

- Protective lung ventilation: To reduce the incidence of perioperative pulmonary complications and improve overall clinical outcomes in TTCS, we used a lung-protective ventilation strategy with a tidal volume (Vt) of 3–3.5 ml $kg^{-1}$ and post end-expiratory pressure (PEEP) levels of 4–6 $cmH_2O$ during single-lung ventilation; if persistent hypoxemia ($PaO_2<60$ mmHg or $SpO_2<90\%$), we can perform bilateral lung ventilation after clamping part of the right tube, which can effectively improve the patient's oxygenation without affecting the surgeon's surgical field, which we called it "1.5 lung ventilation", as shown in Fig. 6.

### 6.3. Post-operative management

- Post-operative pain management: Abundant data have suggested that inadequate postoperative pain control increases morbidity and mortality, and a significant proportion of patients who report severe acute pain will end up suffering from chronic postsurgical pain [27,42]. Despite the small incision in TTCS, postoperative pain management remains very important. In our center, we took a multimodal analgesia strategy that included SAPB and supplemental morphine. Ultrasound-guided SAPB was performed with 30 ml of 0.33% ropivacaine before surgery. The visual analog pain score (VAS) was performed immediately after the patient recovery from anesthesia, and 10 mg of morphine was given when the VAS score was greater than 4, the total consumption per day does not exceed 40 mg.

- Post-operative chest X-ray (CXR): Although efforts and suggestions have been made to reduce the number of post-operative CXR [43], for early detection of postoperative pulmonary complications, all patients in our center received CXR on the first and third day after TTCS, respectively. Antibiotics should be given early if the CXR indicates pneumonia.
- Postoperative follow-up: Patients were telephone followed-up on day 25–30 after TTCS. Numeric rating scales (NRS) was adopted to assess whether patients had chronic pain.

### 6.4. Data collection

All data on demographic details, type of surgery, surgery time, cardiopulmonary bypass (CPB) time, cross-clamp time, intra- and post-operative complications, length of stay (LOS) in the ICU, and LOS on postoperative day (POD) were extracted retrospectively from the medical records.

## Production notes

### Author contribution statement

Hang Tian and Hao Wang: Conceived and designed the experiments.
Yan-jun Chen: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
He Tian: Analyzed and interpreted the data.
Xiao-shen Zhang, Hua Lu and Si Shen: contributed reagents, materials, analysis tools or data;

### Data availability statement

Data included in article/supp. material/referenced in article.

### Declaration of interest's statement

The authors declare no competing interests.

### Additional information

No additional information is available for this paper.

## Financial support and sponsorship

This study was supported by the National Natural Science Foundation, China (Grant No. 82071340), the National Foreign Expert Project of the Ministry of Science and Technology, China (Grant No. G20200019047), Science and Technology Planning Project of Guangdong Province, China (Grant No. 2021A1313030052, 2022A0505050041), Science and Technology Project of Guangzhou, China (Grant No. 202201020027), and Medical Science and Technology Research Fund of Guangdong Province, China (Grant No. A2021392).

## Acknowledgements

Assistance with the study: We thank all the members who participated in this study.

## References

[1] S. Yu, et al., Totally thoracoscopic surgical resection of cardiac myxoma in 12 patients, Ann. Thorac. Surg. 90 (2) (2010) 674–676.
[2] P. Wei, et al., Long-term outcomes of a totally thoracoscopic approach for reoperative mitral valve replacement: a propensity score matched analysis, Ann. Transl. Med. 9 (12) (2021) 987.
[3] Z.S. Ma, et al., Totally thoracoscopic repair of atrial septal defect without robotic assistance: a single-center experience, J. Thorac. Cardiovasc. Surg. 141 (6) (2011) 1380–1383.
[4] Z.S. Ma, et al., Totally thoracoscopic repair of ventricular septal defect: a short-term clinical observation on safety and feasibility, J. Thorac. Cardiovasc. Surg. 142 (4) (2011) 850–854.
[5] L.C. Huang, et al., The use of the Scar Cosmesis Assessment and rating scale to evaluate the cosmetic outcomes of totally thoracoscopic cardiac surgery, J. Cardiothorac. Surg. 15 (1) (2020) 250.
[6] L.H. Cohn, et al., Minimally invasive cardiac valve surgery improves patient satisfaction while reducing costs of cardiac valve replacement and repair, Ann. Surg. 226 (4) (1997) 421–426. ; discussion 427-8.
[7] L.E. Lima, [Minimally invasive cardiac surgery: is it just trend or a method for the future?], Arq. Bras. Cardiol. 68 (2) (1997) 117–118.
[8] L. Cheng, et al., Minimal invasive thoracoscopic mitral valve surgery, Braz. J. Cardiovasc. Surg. 37 (5) (2022) 688–693.
[9] K. Hua, et al., Minimally invasive cardiac surgery in China: multi-center experience, Med. Sci. Mon. Int. Med. J. Exp. Clin. Res. 24 (2018) 421–426.

[10] J.H. Campos, A. Feider, Hypoxia during one-lung ventilation-A review and update, J. Cardiothorac. Vasc. Anesth. 32 (5) (2018) 2330–2338.
[11] C. Durkin, et al., Hypoxemia during one-lung ventilation: does it really matter? Curr. Anesthes. Rep. 11 (4) (2021) 414–420.
[12] J.L. Huffmyer, D.S. Groves, Pulmonary complications of cardiopulmonary bypass, Best Pract. Res. Clin. Anaesthesiol. 29 (2) (2015) 163–175.
[13] A.H. Jufar, et al., Renal and cerebral hypoxia and inflammation during cardiopulmonary bypass, Compr. Physiol. 12 (1) (2021) 2799–2834.
[14] A. Cook, et al., The effect of Preoperative threshold inspiratory muscle training in adults undergoing cardiac surgery on postoperative hospital stay: a systematic review, Physiother. Theory Pract. (2022) 1–14.
[15] E.R. Winkelmann, et al., Preoperative expiratory and inspiratory muscle weakness to predict postoperative outcomes in patients undergoing elective cardiac surgery, J. Card. Surg. 35 (1) (2020) 128–134.
[16] M. Gomes Neto, et al., Pre- and postoperative inspiratory muscle training in patients undergoing cardiac surgery: systematic review and meta-analysis, Clin. Rehabil. 31 (4) (2017) 454–464.
[17] A.L. Cordeiro, et al., Inspiratory muscle training and functional capacity in patients undergoing cardiac surgery, Braz. J. Cardiovasc. Surg. 31 (2) (2016) 140–144.
[18] T. Yan, D. Wang, [Effects of penehyclidine inhalation on postoperative pulmonary complications of elderly patients after long-duration surgery], Zhonghua Yixue Zazhi 94 (2) (2014) 122–126.
[19] G. Li, et al., Cerebral oxygen desaturation in patients with totally thoracoscopic ablation for atrial fibrillation: a prospective observational study, Medicine (Baltim.) 99 (17) (2020), e19599.
[20] F. Holmgaard, et al., The association between postoperative cognitive dysfunction and cerebral oximetry during cardiac surgery: a secondary analysis of a randomised trial, Br. J. Anaesth. 123 (2) (2019) 196–205.
[21] S. Ghosal, et al., Regional cerebral oxygen saturation level predicts 30-day mortality rate after left ventricular assist device surgery, J. Cardiothorac. Vasc. Anesth. 32 (3) (2018) 1185–1190.
[22] F. Hayashi, et al., Early detection of cerebral ischemia due to pericardium traction using cerebral oximetry in pediatric minimally invasive cardiac surgery: a case report, JA Clin. Rep. 5 (1) (2019) 53.
[23] Bender, S.P., et al., One-lung ventilation and acute lung injury. Int. Anesthesiol. Clin.. 56(1): p. 88-106.
[24] A. Dulu, et al., Prevalence and mortality of acute lung injury and ARDS after lung resection, Chest 130 (1) (2006) 73–78.
[25] L.F. Barr, et al., Postoperative multimodal analgesia in cardiac surgery, Crit. Care Clin. 36 (4) (2020) 631–651.
[26] B. Nachiyunde, L. Lam, The efficacy of different modes of analgesia in postoperative pain management and early mobilization in postoperative cardiac surgical patients: a systematic review, Ann. Card Anaesth. 21 (4) (2018) 363–370.
[27] J.C. Krakowski, M.J. Hallman, A.M. Smeltz, Persistent pain after cardiac surgery: prevention and management, Semin. CardioThorac. Vasc. Anesth. 25 (4) (2021) 289–300.
[28] T.J. Caruso, K. Lawrence, B.C.H. Tsui, Regional anesthesia for cardiac surgery, Curr. Opin. Anaesthesiol. 32 (5) (2019) 674–682.
[29] D.E. Torre, et al., Ultrasound-guided PECS II + serratus plane fascial blocks are associated with reduced opioid consumption and lengths of stay for minimally invasive cardiac surgery: an observational retrospective study, Life 12 (6) (2022).
[30] D.H. Kim, et al., Efficacy of ultrasound-guided serratus plane block on postoperative quality of recovery and analgesia after video-assisted thoracic surgery: a randomized, triple-blind, placebo-controlled study, Anesth. Analg. 126 (4) (2018) 1353–1361.
[31] B.S. Silbert, P.S. Myles, Is fast-track cardiac anesthesia now the global standard of care? Anesth. Analg. 108 (3) (2009) 689–691.
[32] D.C. Cheng, et al., Early tracheal extubation after coronary artery bypass graft surgery reduces costs and improves resource use. A prospective, randomized, controlled trial, Anesthesiology 85 (6) (1996) 1300–1310.
[33] R. Bhavsar, et al., Fast-track cardiac anaesthesia protocols: is quality pushed to the edge? Ann. Card Anaesth. 23 (2) (2020) 142–148.
[34] P. Lloyd-Donald, et al., Fast-track recovery program after cardiac surgery in a teaching hospital: a quality improvement initiative, BMC Res. Notes 14 (1) (2021) 201.
[35] T. Doenst, J. Lamelas, Do we have enough evidence for minimally-invasive cardiac surgery? A critical review of scientific and non-scientific information, J. Cardiovasc. Surg. 58 (4) (2017) 613–623.
[36] C.R. Freitas, et al., Lung perfusion and ventilation during cardiopulmonary bypass reduces early structural damage to pulmonary parenchyma, Anesth. Analg. 122 (4) (2016) 943–952.
[37] C. Liang, et al., The fraction of nitrous oxide in oxygen for facilitating lung collapse during one-lung ventilation with double lumen tube, BMC Anesthesiol. 20 (1) (2020) 180.
[38] J. Neumann, et al., Surgical workflow simulation for the design and assessment of operating room setups in orthopedic surgery, BMC Med. Inf. Decis. Making 20 (1) (2020) 145.
[39] O. Sen, et al., Robotic-assisted cardiac surgery without lung isolation utilizing single-lumen endotracheal tube intubation, J. Card. Surg. 35 (6) (2020) 1267–1274.
[40] S. Senay, A.U. Gullu, C. Alhan, Robotic mitral valve replacement for rheumatic mitral disease, Ann. Cardiothorac. Surg. 6 (1) (2017) 64–66.
[41] F.S. Saad, et al., Ultrasound-guided serratus anterior plane block versus thoracic paravertebral block for perioperative analgesia in thoracotomy, Saudi J. Anaesth. 12 (4) (2018) 565–570.
[42] S. Nazarnia, K. Subramaniam, Nonopioid analgesics in postoperative pain management after cardiac surgery, Semin. CardioThorac. Vasc. Anesth. 25 (4) (2021) 280–288.
[43] K. Grapatsas, et al., Can chest ultrasound replace chest X-ray in thoracic surgery? Tomography 8 (4) (2022) 2083–2092.