Selective right middle and lower lobar blockade for minimally invasive cardiac surgery: a prospective, single-center, randomized controlled study

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Background: Minimally invasive cardiac surgery (MICS) is increasingly performed due to faster recovery time and lower postoperative complications when compared with the traditional open surgery. However, hypoxemia in lung isolation duration after cardiopulmonary bypass (CPB) surgery has been the focus of anesthesiologists' attention. In the present study, we designed a novel lung isolation strategy to improve oxygenation using a bronchial blocker (BB) to isolate the right middle and lower lobes and preserve the ventilated right upper lobe without affecting the surgical field.

Methods: Patients who had undergone right lateral mini-thoracotomy, a MICS, between August 2018 and February 2019, were enrolled in this randomized controlled study. Patients were randomly divided into a modified lung isolation group (group M) and a conventional lung isolation group (group C). In group M, BBs were used to block the bronchus intermedius, while left-sided double lumen endotracheal tubes were used in group C to isolate the right lung. The primary outcome was to determine the number of patients who required an increase in ventilation volume due to hypoxemia during lung isolation after CPB.

Results: Sixty-one patients (30 in group C and 31 in group M) were enrolled. Five patients in group M were converted to right lung isolation due to poor surgical field exposure. During lung isolation after CPB, the number of patients with hypoxemia was lower in group M than group C (5/31 *vs.* 15/30, P=0.005).

Conclusions: The novel modified lung isolation strategy reduced the incidence of hypoxemia after CPB.

Keywords: Minimally invasive cardiac surgery (MICS); lung isolation; one-lung ventilation; hypoxemia; selective lobar blockade (SLB)

Introduction

Minimally invasive cardiac surgery (MICS) through right lateral mini-thoracotomy may be an alternative to conventional surgery for patients with mitral valve disease (1). Compared with open surgery, MICS has greater advantages, such as fewer blood transfusion and shorter hospital stay (2), and increasingly more cardiac centers are now performing this surgery as a routine procedure (3).

MICS via the right chest typically requires lung isolation for surgical field exposure, which can be achieved by a double-lumen endotracheal tube (DLT) or a single-lumen endotracheal tube with a bronchial blocker (BB). However, hypoxemia is associated with one-lung ventilation (OLV) after cardiopulmonary bypass (CPB) (4). The surgical

Page 2 of 11

Ren et al. Selective right blockade in MICS

position of MICS patients also increases intrapulmonary shunt due to the smaller ventilation volume by the left lung (5). Moreover, CPB induces hemodilution, lung interstitial edema, and lung ischemia–reperfusion injury, which impact on pulmonary function and are associated with a significant reduction in oxygenation after CPB (6). Interventions of hypoxemia during OLV include recruitment maneuver, positive end-expiratory pressure (PEEP) to the ventilated lung, and continuous positive airway pressure (CPAP) to the remaining lung. In some patients, hypoxemia cannot be reversed by these methods, nor with FiO_2 1.0. Therefore, anesthesiologists often choose double-lung ventilation (DLV) to maintain oxygenation and the surgical procedure is interrupted.

Patients who had previously undergone contralateral lung lobectomy might be at risk of hypoxemia during OLV due to the limited ventilation volume. For these patients, BB's selective lobar blockade (SLB) should be the preferred ventilation strategy (7). Mini-thoracotomy, which is a MICS, is performed in the fourth intercostal space, where the middle and lower lobes of the right lung are located. In the present study, we present a novel modified lung isolation strategy by blocking the right middle and lower lobes and preserving the right upper lobe. We compared this modified lung isolation strategy with conventional OLV by DLT.

We present the following article following the CONSORT reporting checklist (available at http://dx.doi.org/10.21037/atm-20-986).

Methods

Research population

The present study was a prospective, randomized controlled trial. Patients were enrolled between August 2018 and February 2019. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the Ethics Committee of Zhongshan Hospital, Fudan University (approval number: B2016-022R). All patients provided signed informed consent. The study has been registered on the Clinical trials website (registration number: NCT03505242).

Inclusion and exclusion criteria

The inclusion criteria were as follows: (I) 18–70 years of age; (II) European System for Cardiac Operative Risk Evaluation II 0–5; and (III) scheduled to undergo elective MICS through right lateral mini-thoracotomy and femoral cannulation for CPB.

The exclusion criteria were as follows: (I) body mass index >30 kg/m^2; (II) coronary artery disease; (III) chronic obstructive pulmonary disease or asthma; (IV) previous thoracic or cardiac surgery; (V) infectious endocarditis; and (VI) predicted difficult airway.

Patient allocation

Enrolled patients were randomly divided into 2 groups (computerized random number, https://www.randomizer.org) 1 day before surgery: a conventional lung isolation strategy group (group C) and a modified lung isolation strategy group (group M). DLTs were used for lung isolation in group C, while BBs were used in group M to block the bronchus intermedius for the right middle and lower lobes collapse during lung isolation.

Anesthesia

Patients were monitored with an electrocardiogram and pulse oximetry; a central vein catheter and radial artery catheter were then cannulated. Sufentanil, propofol, and rocuronium were used for induction, following tracheal intubation with a Macintosh laryngoscope (Truphatek International Ltd., Netanya, Israel). Intraoperative transesophageal echocardiography was used for all patients. Sevoflurane inhalation (propofol infusion during CPB) was adopted to maintain intraoperative amnesia, along with sufentanil and rocuronium for analgesia and muscle relaxation.

Airway management strategy

Lung isolation method

In group C, the left main bronchus diameter was measured by preoperative chest computed tomography. The 35F left DLT was selected when the diameter ≤11 mm, the 37F DLT, was used for 11–12 mm, and the 39F DLT was used for >12 mm. After intubation, pediatric fiberoptic bronchoscopy (FOB) was applied for appropriate position confirmation. In group M, the ID 8-mm tracheal tube was selected for male patients, and the ID 7.5-mm tracheal tube was selected for female patients. After intubation, FOB was applied to measure the tracheal tube's depth to ensure that the tip of the tube was placed 3–4 cm away from the main carina. The BB's cuff was placed in the bronchus
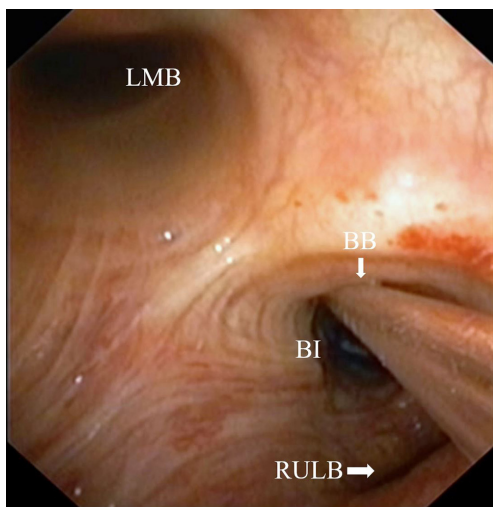
Figure 1 View under fiber optic bronchoscopy. The cuff of BB was placed in the bronchus intermedius with the right middle and lower lobes collapsed and ventilation of the right upper lobe preserved. LMB, left main bronchi; BI, bronchus intermedius; RULB, right upper lobar bronchus; BB, bronchial blocker.
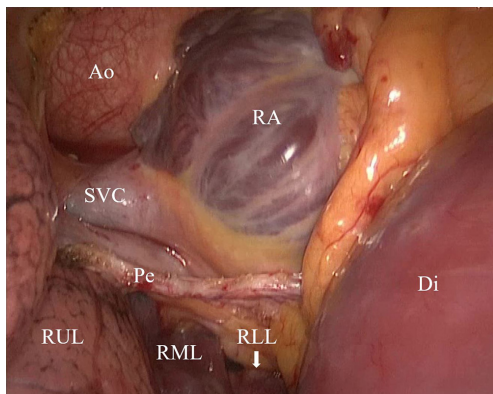
Figure 2 View under thoracoscope. After selective lobar blockade, the right middle and lower lobes collapsed. Ventilation of the right upper lobe was preserved and the surgical field exposure was not affected. Ao, aorta; RA, right atrium; SVC, superior vena cava; Pe, pericardium; Di, diaphragm; RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe.

intermedius with the guidance of FOB (*Figure 1*). The cuff position was reconfirmed by auscultation in both groups. All procedures were performed by an attending anesthesiologist who had experience in 10 cases for each method. Also, we recorded the time between the start of the tracheal intubation to the end of lung isolation confirmation.
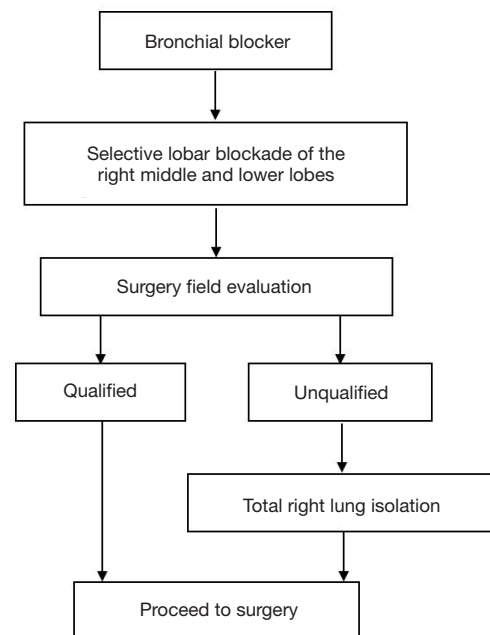
Figure 3 Strategy of modified lung isolation for minimally invasive cardiac surgery.

For pleurectomy to commence, apnea had to last for 1 min in both groups, and the bronchial cuffs in both groups were then inflated to start lung isolation. After the retractor was fixed between the ribs, group M's surgical field exposure was evaluated (*Figure 2*). If the inflated right upper lobe affected the ascending aorta and aortic root's surgical exposure, mechanical ventilation was suspended for pericardial traction (if hypoxemia occurred during this period, manually controlled DLV with a small tidal volume was applied to assist the pericardial traction). The surgical field exposure was reassessed after restarting mechanical ventilation. If the exposure was still unsatisfactory, the SLB was changed to right lung isolation (*Figure 3*). Times of intraoperative dislodgement or loss of seal were also recorded.

Intraoperative mechanical ventilation

After tracheal intubation, volume-controlled mechanical ventilation mode without PEEP was initiated at FiO_2 1.0, with oxygen flow at 2 L/min. During DLV, Tidal volume was 8 mL/kg (ideal body weight), and the initial respiratory rate was 10/min. Tidal volume during lung isolation was 6 mL/kg (ideal body weight), and the initial respiratory rate was 12/min. The inspiratory pause was set to 20% of the total inspiratory time, and the respiratory rate

Page 4 of 11

Ren et al. Selective right blockade in MICS

was adjusted to maintain end-tidal CO_2 at 40 ± 5 mmHg. Mechanical ventilation was stopped during intracardiac surgical procedures in CPB. Ventilation with lung isolation continued after the aortic unclamping, and the bilateral lung recruitment (pressure 40 cmH_2O for 20 s, the same standard as follows) was performed before CPB weaning. The bloody secretion from the airway suction was defined as airway bleeding. When the surgery was completed, patients in group C were reintubated with a single-lumen endotracheal tube. At the same time, BB was removed in group M. After bilateral lung recruitment, the patients were transferred to the intensive care unit (ICU) for continued respiratory support.

Interventions for hypoxemia

Hypoxemia was defined as SpO_2 <90%. If hypoxemia occurred during lung isolation, a recruitment maneuver (same standard as described above) was performed to the ventilated lung, and then ventilation under lung isolation continued with 5 cmH_2O PEEP. DLV was implemented if hypoxemia had not resolved. Lung isolation was restarted when SpO_2 >95%, and then CPAP of 5 cmH_2O was applied to the remaining lung. DLV was directly implemented if hypoxemia occurred in the next lung isolation period.

Surgery and CPB procedure

The patient was placed in the supine position with a wedge under the right chest. The femoral artery and vein were cannulated to establish CPB. After incision at the fourth intercostal space and pericardium traction, CPB commenced. The priming solution contained 1,500 mL Lactated Ringer's injection, 500 mL Gelofusine, and 100 mL of 20% albumin. A target body temperature of 32 ℃ and non-pulsating perfusion utilizing a roller pump was adopted.

Furthermore, α state was used for blood gas management. After aortic clamping and antegrade perfusion of blood-containing del Nido cardioplegia (8), surgery was performed through the interatrial groove or the right atrial incision. After rewarming, norepinephrine, dobutamine, and milrinone were transfused to assist weaning from CPB if necessary. Conventional ultrafiltration was performed during CPB with a target amount of priming fluid, cardioplegia, and surgical rinsing saline. Residual blood in the surgical field and circuit were collected in an autotransfusion system (Cell Saver Elite; Haemonetics).

After the hemostasis was completed, a chest tube was placed, and the incision was closed.

Data collection

The respiratory rate, peak airway pressure (P_{peak}), and plateau pressure (P_{plat}) during DLV and lung isolation were recorded in both groups before and after CPB. Blood gas analysis and PaO_2/FiO_2 were collected 4 times. T_0 indicated data before anesthesia induction (FiO_2 0.21), T_1 indicated data at 10 min after weaning from CPB (if DLV were performed due to hypoxemia within 10 min, the sample would be collected when the lowest SpO_2 occurred in the next lung isolation period), T_2 indicated data after bilateral lung recruitment at the end of the surgery, and T_3 indicated data 24 h after surgery. The operation duration, CPB, aortic clamping, and surgical hemostasis (time between weaning from CPB to the end of surgery), along with volumes, including ultrafiltration, fluid infusion, blood transfusion, and urine, were recorded. The minimum hemoglobin level and the maximum creatinine and cardiac troponin T levels after surgery were also recorded.

Primary and secondary endpoints

The primary endpoint was to determine the number of patients who required recruitment maneuvers on the ventilated lung due to hypoxemia during lung isolation after CPB.

The secondary endpoints were to determine the number of patients who required DLV due to hypoxemia during lung isolation after CPB; the time between the start of tracheal intubation to definite confirmation of the position of the lung isolation device, airway bleeding, and dislodgement; the differences in P_{peak} and P_{plat} during DLV and lung isolation; PaO_2/FiO_2 at T_0, T_1, T_2, and T_3 and differences between groups; and evaluation of surgical field exposure [as scored by the surgeon after surgery (1–5 points, 1 indicating worst exposure and 5 indicating best exposure)].

Sample size calculation

Approximately 40% of patients suffered hypoxemia during lung isolation with DLTs after CPB (unpublished data). However, according to our clinical experience, hypoxemia rarely occurs after CPB with the successful application of an SLB. Assuming that the modified lung isolation strategy could reduce hypoxemia by 75%, 29 patients were required in each group when simulating the probability of α=0.05
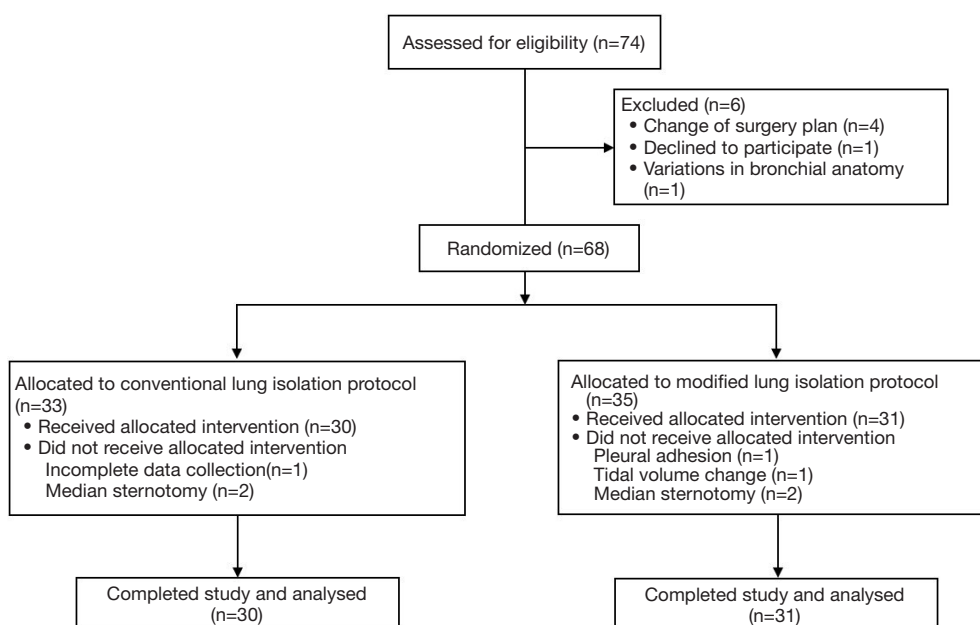
Figure 4 CONSORT diagram. CONSORT, consolidated standards of reporting trials.

and β=0.2. Considering a 20% loss, the number of selected patients in each group was 37.

Statistical analysis

Statistical analysis was performed using SPSS version 25.0 software (IBM, Armonk, NY, USA). Data with normal distribution were expressed as mean ± standard deviation, and those with non-Gaussian distribution were expressed as median and interquartile range. Discrete data were analyzed using the χ^2-test or Fisher's exact test. Continuous data were compared using an independent sample t-test or Mann-Whitney U-test. P<0.05 was considered statistically significant.

Results

A total of 74 patients were included in the present study. Of these, 6 were excluded and 68 were randomized; 33 cases were assigned to the group C, and 3 were excluded, and 35 cases were assigned to group M, and 4 cases were excluded (*Figure 4*). No statistical differences were observed for baseline characteristics, comorbidities, preoperative evaluations, and surgery types (*Table 1*).

The number of cases in which lung recruitment was performed due to hypoxemia during lung isolation after CPB in group C (50%, 15/30) was significantly greater

than in group M (16.1%, 5/31, P=0.005). The number of cases requiring DLV in group C (36.7%, 11/30) was notably greater when compared with group M (6.5%, 2/31) (P=0.004). The time for intubation and position confirmation in group M was prominently longer than group C {390 [344–480] s *vs.* 221 [179-278] s}. Furthermore, dislodgements in both groups were similar (6 *vs.* 7). There were 4 cases of airway bleeding in group C and 3 in group M. Surgical field exposure was 5 [4.3–5] in group C, which was higher than that of group M {4 [4–5], P=0.012} (*Table 2*).

Five patients in group M were changed to right lung isolation due to poor surgical field exposure. However, after excluding these cases, we also compared patients who successfully underwent SLB in group M (n=26) with group C. The statistical significance of lung isolation-related parameters was the same as the previous result (*Table 2*). There were significant increases in the value of P_{peak} and P_{plat} during lung isolation in group C, which were higher than that of group M (n=26) before and after CPB (P=0.002 and P<0.001 *vs.* P=0.008 and P<0.001, respectively) (*Table 3*).

Surgical hemostasis time was 47.5 [45–67] min in group C and 55 [47.5–63.5] min in group M (P=0.294). Also, there was no significant difference in the following parameters: time durations of surgery, CPB, and aortic clamping and in the volumes of fluid infusion, ultrafiltration, and urine output. The minimum hemoglobin level measured in group C was 103.7±16.3 g/L, which was not significantly

Page 6 of 11

Ren et al. Selective right blockade in MICS

Table 1 Demographic and patients characteristics

Characteristics	Group C (n=30)	Group M (n=31)	P value
Female sex	20 (66.7%)	18 (58.1%)	0.488
Age (yr)	53.0 [45.3–58.8]	54.0 [40.5–61.5]	0.914
EuroSCORE II	1 [0–1]	1 [1–1.5]	0.732
Height (cm)	162.1±8.2	164.0±7.4	0.758
Weight (kg)	60.2±9.5	61.6±8.7	0.558
BMI index (kg·m^{-2})	22.9±2.5	22.8±2.2	0.947
NYHA score			0.219
NYHA I	10 (33.3)	8 (25.8)	
NYHA II	11 (36.7)	18 (58.1)	
NYHA III	9 (30.0)	5 (16.1)	
Comorbidities			
Sleep apnea	4 (13.3%)	3 (9.6%)	0.654
Current smoker	4 (13.3%)	7 (22.5%)	0.348
Drinking	6 (20.0%)	6 (19.4%)	0.949
Recent URI	3 (10%)	4 (12.9%)	0.722
Hypertension	8 (26.7%)	7 (22.6%)	0.711
Diabetes	1 (3.3%)	2 (6.5%)	0.573
Perioperative data			
LVEF (%)*	66.8±5.5	66.5±4.2	0.763
Pulmonary artery pressure (mmHg)*	44.1±11.4	40.9±12.3	0.146
Chronic pneumonia in chest CT	17 (56.7%)	13 (41.9%)	0.250
Hemoglobin (g/L)	134.1±17.8	131.4±15.0	0.516
Albumin (g/L)	41.7±3.0	41.9±3.1	0.887
Creatinine (μmol/L)	74.7±19.4	76.1±18.4	0.769
cTnT (ng/mL)	0.010 [0.003–0.010]	0.010 [0.007–0.010]	0.295
Surgery			
MVR	12 (40%)	7 (22.6%)	0.142
MVP	13 (43.3%)	19 (61.3%)	0.160
ASD	3 (10%)	2 (6.5%)	0.614
Atrial myxoma resection	2 (6.7%)	3 (9.7%)	0.668

*, according to echocardiography. EuroSCORE, European system for cardiac operative risk evaluation; URI, upper respiratory infection; LVEF, left ventricular ejection fraction; cTnT, cardiac troponin T; MVR, mitral valve replacement; MVP, mitral valvuloplasty; ASD, atrial septal defect.

Table 2 Lung isolation related parameters

Characteristics	Group C (n=30)	Group M (n=31)*	P value	Group M (n=26)[†]	P value[‡]
Recruitment maneuver on the ventilated lung	15 (50.0%)	5 (16.1%)	0.005	5 (19.2%)	0.017
Double lung ventilation	11 (36.7%)	2 (6.5%)	0.004	2 (7.7%)	0.010
Time for intubation and positioning (seconds)	221 [179–278]	390 [344–480]	<0.001	390 [330–452]	<0.001
Dislodgement	6 (20.0%)	7 (22.6%)	0.804	5 (19.2%)	0.942
Airway bleeding	4 (13.3%)	3 (9.7%)	0.725	1 (3.8%)	0.214
Evaluation of surgical field exposure	5 [4.3–5]	4 [4–5]	0.012	4 [4–5]	0.036

*, all cases in Group M; [†], cases in Group M with acceptable surgical field exposure; [‡], Group M (n=26) *vs*. Group C.

Table 3 Peak airway pressures (P_{peak}) and platform pressures (P_{plat}) (cmH_2O)

Time	Ventilation mode	Characteristics	Group C (n=30)	Group M (n=26)[†]	P value
Before CPB	DLV	P_{peak}	16.1±3.1	16.3±3.4	0.788
		P_{plat}	12.6±2.2	12.3±2.6	0.686
	Lung isolation	P_{peak}	20.8±4.7	17.3±3.5	0.002
		P_{plat}	16.3±4.2	13.7±2.8	0.008
After CPB	DLV	P_{peak}	17.7±4.8	17.5±4.8	0.873
		P_{plat}	13.7±4.3	13.7±4.4	0.991
	Lung isolation	P_{peak}	22.0±4.2	16.8±4.5	<0.001
		P_{plat}	17.4±4.2	13.1±4.1	<0.001

[†], cases in Group M with acceptable surgical field exposure. CPB, cardiopulmonary bypass; DLV, double lung ventilation.

different from 103.9±12.6 g/L in group M (P=0.957). There was no perioperative allogeneic blood transfusion in either group. We found no significant differences in levels of postoperative maximum serum creatinine and cardiac troponin T and in the duration of postoperative mechanical ventilation, ICU discharge, and hospitalization between both groups (*Table 4*).

When comparing patients who successfully underwent SLB in group M (n=26) with group C, no significant difference in PaO_2/FiO_2 at T_0, T_2, and T_3 (P=0.605, P=0.642, and P=0.801) was observed. PaO_2/FiO_2 at T_1 in group C was 93.9±31.4 mmHg, which lower than group M (119.2±52.3 mmHg, P=0.038). PaO_2/FiO_2 at T_1, T_2, and T_3 were inferior to T_0 in both groups (P<0.01) (*Table 5*).

Discussion

In the present study, we found that PaO_2/FiO_2 was markedly lower than the preoperative baseline after CPB, even with DLV. Hypoxemia occurred in 50% of patients

undergoing right lung isolation, while 36.7% required DLV to maintain oxygenation. Accordingly, satisfactory field exposure based on adequate oxygenation poses a challenge for anesthesiologists. The modified lung isolation strategy reduced the incidence of hypoxemia during lung isolation after CPB.

Although hypoxemia did not occur in all cases, the modified lung isolation strategy appeared to be more beneficial for patients with poor preoperative respiratory function and those at risk of hypoxemia during lung isolation after CPB. At the same time, SLB provides continuous lung isolation, which may be more appropriate for unskilled surgeons (9), as they can operate without the possibility of hypoxemia affecting the patient's safety during surgery.

BB was previously used for lung isolation in MICS (10), with only the right main bronchus blocked to achieve the right lung collapse. This might fail to treat possible hypoxemia after CPB, whereas SLB can notably increase the oxygenation index (11). In the case of robot-assisted

Page 8 of 11

Ren et al. Selective right blockade in MICS

Table 4 Intraoperative and postoperative data

Characteristics	Group C (n=30)	Group M (n=31)	P value
Intraoperative data			
Operation time (min)	190.0 [169.3–210.8]	190.0 [161.0–218.5]	0.977
CPB time (min)	101.0 [85.8–116.8]	83.0 [67.5–111.0]	0.060
Aortic cross clamping time (min)	57.5 [41.8–70.8]	46.0 [37.0–60.0]	0.085
Surgical hemostasis time (min)	47.5 [45.0–67.0]	55.0 [47.5–63.5]	0.294
Fluid volume (mL)	1,450 [1,200–1,700]	1,400 [1,200–1,600]	0.749
Ultrafiltration volume (mL)	2,550 [2,275–3,000]	2000 [2,000–3,000]	0.089
Urine output (mL)	325 [213–500]	400 [250–550]	0.139
Postoperative data			
Time of postoperative mechanical ventilation (hr)	14.4 [11.9–19.2]	11.8 [5.5–18.7]	0.251
Time of ICU discharge (hr)	21.3 [16.0–22.8]	20.4 [17.1–23.6]	0.823
Duration of hospitalization (days)	5 [5–6.8]	6 [5–7]	0.865
Minimum hemoglobin (g/L)	103.7±16.3	103.9±12.6	0.957
Maximum cTnT (ng/mL)	0.360 [0.273–0.520]	0.240 [0.210–0.475]	0.145
Maximum creatinine (umol/L)	86.3±27.8	81.9±27.1	0.534

CPB, cardiopulmonary bypass.

Table 5 PaO_2/FiO_2 (mmHg)

Time	Conventional Group (n=30)	Modified Group (n=26)[†]	P value
T_0	424.7±67.1	416.2±52.9	0.605
T_1	93.9±31.4*	119.2±52.3*	0.038
T_2	311.5±107.9*	325.6±117.3*	0.642
T_3	359.7±105.3*	366.9±107.0*	0.801

[†], cases in Group M with acceptable surgical field exposure. T_0 indicated data before anesthesia induction (FiO$_2$ 0.21). T_1 indicated data at 10 minutes after weaning from CPB (if DLV was performed due to hypoxemia within 10 minutes, data would be collected when the lowest SpO$_2$ occurred in the next lung isolation period). T_2 indicated data after bilateral lung recruitment at the end of surgery and T_3 for 24 hours after surgery. *, vs. T_0 in each group, P<0.01.

coronary artery bypass grafting, the patient can encounter severe hypoxemia when the BB is used to isolate the left lung. Subsequently, BB's cuff was placed forward into the left upper lobe bronchus for SLB, after which hypoxemia was resolved and it was possible to proceed with the operation (12). We first attempted to apply SLB in MICS through right lateral mini-thoracotomy with BB blocking the bronchus intermedius (*Figure 5*).

With the ventilated right upper lobe, PaO_2/FiO_2 during lung isolation after CPB was significantly higher in group M than group C; however, it was quite low. Besides the impact of CPB, it might be due to rare lung recruitment in group M, FiO$_2$ 1.0, and relatively low tidal volume during lung isolation without PEEP, all of which resulted in atelectasis and affected oxygenation (13). With the increased volume of the right upper lobe in group M, P_{peak} and P_{plat} values in group M were remarkably lower than those in group C under the same tidal volume setting, reducing the collapsed lung volume and incidence of lung injury (14).

Field exposure was important for surgical hemostasis, along with no difference in postoperative minimum hemoglobin level and hemostasis time between the 2 groups in our study. The surgical field evaluation score was lower in group M than group C. This could be due to surgeons feeling more comfortable operating in the cavity with the collapsed whole right lung and the original narrow vision becoming increasingly squeezed by the inflated right upper lobe, even when the operation targets were not covered. Also, for 5 cases in group M, the right upper lobe occluded the field at both inspiratory and expiratory phases, indicating that SLB might not be suitable for all patients.
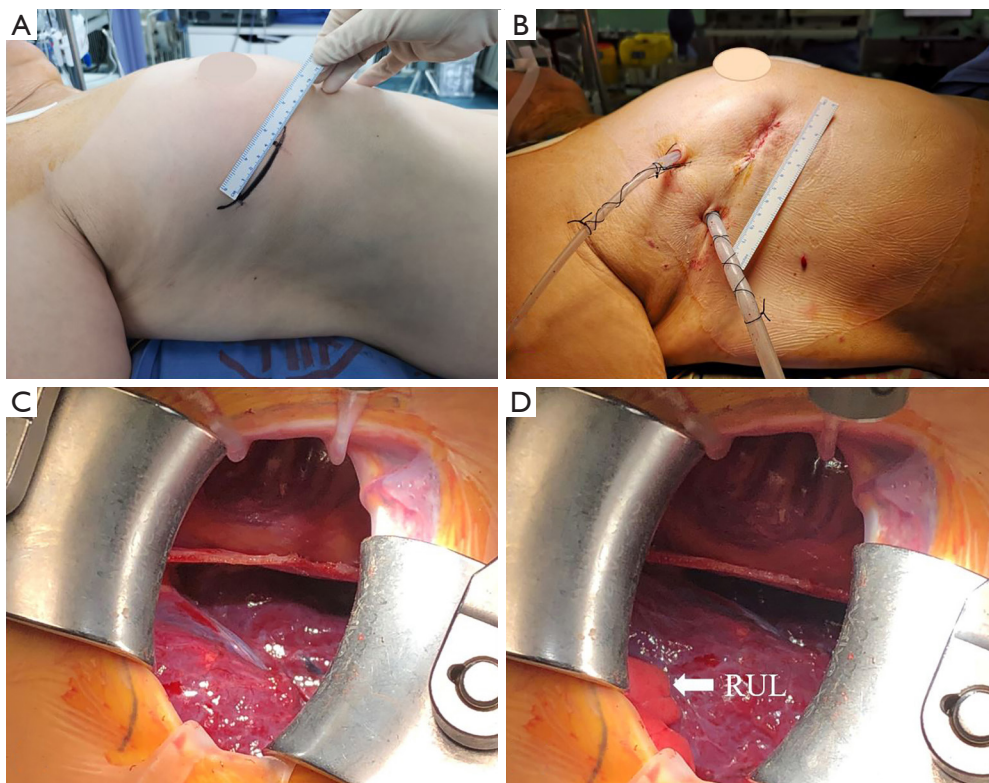
Figure 5 Patient position and surgical fields. (A) Patient position and incision mark of right lateral mini-thoracotomy; (B) Incision after surgery; (C) surgical field at the end of expiration, RUL was not showed; (D) surgical field at the end of inspiration, RUL was partly showed. RUL, right upper lobe.

However, the exposure significantly improved after the BB cuff was retracted to the right main bronchus.

The advantages of DLT for lung isolation include absolute lung separation, easy suction, convenient and reliable conversion between OLV, and DLV. The disadvantages include difficulty selecting the appropriate size, unsuitability for difficult airways, and possible tracheobronchial injury. BB's advantages include easy recognition of the carina anatomy through the trachea, suitability for difficult airway, and unnecessity to replace a tracheal tube after surgery. The disadvantages include difficult suction and potential dislodgement or loss of seal (15). It takes more time for BB to acquire a suitable position for lung isolation (16). Although lung isolation by the BB is a basic skill for anesthesiologists, the option may not be routine in clinical practice and requires a learning curve (17). When SLB is implemented, the time for positioning inevitably increases. The operation time is relatively shortened without replacing DLT with a single-lumen endotracheal tube after surgery. Airway edema can also occur after cardiac surgery, leading to the risk of replacing the endotracheal tube, where the BB has a prominent advantage (18). Also, we found no differences in airway bleeding and dislodgement, further supporting the modified lung isolation strategy's safety and efficacy.

The present study has some limitations. First, the surgeons were not blinded to the interventions. Furthermore, the evaluation for surgical field exposure was based on subjective feelings and lacked objective evidence for lung collapse (19). This could have biased the evaluation. Second, a previously published study showed no difference in the time taken to replace a DLT with a single-lumen endotracheal tube using an exchange catheter compared to the BB, which was related to operation room efficiency (10). We did not collect related time data in our study, so lacking of the data to analyses the difference between two study groups. Finally, a recent study showed that the incidence of postoperative sore throat and hoarseness in patients using the BB were lower than DLT (20). In our study, patients in group C were reintubated with an accustomed single-lumen tracheal tube with a smaller

Page 10 of 11

Ren et al. Selective right blockade in MICS

size than that of group M (7.5# for males, 7.0# for females), so no relevant follow-up was performed.

Conclusions

The novel modified lung isolation strategy reduced hypoxemia during lung isolation after CPB in patients who underwent right lateral mini-thoracotomy, a MICS.

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Footnote

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Ethics Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The present study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the Ethics Committee of Zhongshan Hospital, Fudan University (approval number: B2016-022R). All patients provided signed informed consent.

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