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Minimal volume ventilation during robotically assisted mitral valve surgery

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Abstract

Introduction: A minimal volume ventilation method for robotically assisted mitral valve surgery is described in this study. In an attempt to reduce postoperative pulmonary dysfunction, 40 of 174 patients undergoing robotically assisted mitral valve surgery were ventilated with a small tidal volume during cardiopulmonary bypass.

Methods: After propensity score matching, 31 patients with minimal volume ventilation were compared with 54 patients with no ventilation. Total ventilation time, PaO_2/FiO_2 ratio, arterial lactate concentration, and the rate of unilateral pulmonary edema in the matched minimal ventilation and standard treatment groups were evaluated.

Results: Patients in the minimal ventilation group had shorter ventilation times, 12.0 (interquartile range: 9.9-15.0) versus 14.0 (interquartile range: 12.0-16.3) hours ($p = 0.036$), and lower postoperative arterial lactate levels, 0.99 (interquartile range: 0.81-1.39) versus 1.28 (interquartile range: 0.99-1.86) mmol/L ($p = 0.01$), in comparison to patients in the standard treatment group. There was no difference in postoperative PaO_2/FiO_2 ratio levels or in the rate of unilateral pulmonary edema between the groups.

Conclusion: Minimal ventilation appeared beneficial in terms of total ventilation time and blood lactatemia, while there was no improvement in arterial blood gas measurements or in the rate of unilateral pulmonary edema. The lower postoperative arterial lactate levels may suggest improved lung perfusion among patients in the minimal volume ventilation group. The differences in the ventilation times were in fact small, and further studies are required to confirm the possible advantages of the minimal volume ventilation method in robotically assisted cardiac surgery.

Keywords

anesthesia; minimally invasive surgery; mitral valve; perioperative care; pulmonary function; robotics; ventilation

Introduction

Minimally invasive and robotically assisted methods have been increasingly utilized in cardiac surgery. Robotically assisted methods have been most commonly adopted in mitral valve operations, while robotic coronary artery bypass grafting, robotic atrial septal defect closures, and robotic myxoma excisions have also been performed. In many series, the safety and outcomes of robotically assisted cardiac operations have been comparable to the results of conventional sternotomy operations.[1–8]

In robotically assisted operations, cardiopulmonary bypass (CPB) is accomplished via the femoral artery and vein, and aortic occlusion is performed either with an endoaortic balloon or directly with the Chitwood clamp transthoracically. In robotically assisted mitral valve surgery, exposure is obtained from a right minithoracotomy. The right lung is collapsed to gain surgical access to the heart, requiring simultaneous ventilation of the left lung. One-lung ventilation (OLV) is accomplished using either a double-lumen endotracheal tube or a bronchial blocker.

Minimally invasive cardiac surgery with OLV has been associated with postoperative pulmonary dysfunction

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and postoperative unilateral pulmonary edema (UPE) of the collapsed lung with high morbidity and mortality.[9–15] The patophysiology of UPE is unknown, but previous studies have hypothesized that ischemia-reperfusion might contribute to the development of UPE.[9,10,14] Even though blood flow to the collapsed lung is reduced physiologically by hypoxic pulmonary vasoconstriction to minimize transpulmonary shunting, part of the blood flow is shunted via the collapsed lung predisposing to hypoxemia. Inferior PaO_2/FiO_2 ratios after CPB have been reported among patients operated using OLV in comparison to double-lung ventilation.[16]

Increased CPB duration has been associated with elevated postoperative lactate levels[17–20] and increased morbidity and mortality among patients undergoing cardiac surgery from sternotomy.[17,18,20] Notably, the lungs have been shown to be a significant source of lactate production during cardiac surgery.[19,21]

In cardiac surgery with the sternotomy approach, the effects of continuous positive airway pressure (CPAP) and mechanical ventilation during CPB on postoperative oxygenation and pulmonary dysfunction have been previously evaluated with varying results and also recent meta-analyses have been published.[22,23] In the meta-analyses, CPAP during CPB has improved postoperative oxygenation without any effect on the clinical outcomes. In thoracic surgery with OLV, improved postoperative oxygenation, reduced pulmonary shunting, and reduced local inflammatory response in the affected lung have been reported after CPAP or high-frequency jet ventilation (HFJV) during CPB.[24–28] Also, adding positive end-expiratory pressure (PEEP) to the ventilated lung may enhance oxygenation during OLV.[29,30]

In robotically assisted mitral valve surgery, the use of CPAP or PEEP during CPB is not feasible due to the resulting restricted visibility in the surgical field. Therefore, ventilation of the lungs with a small tidal volume during CPB without PEEP (minimal volume ventilation (MVV)) was adopted in our institution in an attempt to reduce postoperative hypoxemia and UPE. Both lungs of 40 of 174 patients undergoing robotically assisted mitral valve surgery were ventilated with a small tidal volume during CPB. To assess the potential benefits of MVV, total ventilation time, postoperative PaO_2/FiO_2 ratio, arterial lactate concentration, and the rate of UPE were evaluated. Propensity score matching (PSM) was utilized to compare MVV patients and patients who were not ventilated during CPB (standard treatment group).

Methods

Patients and data collection

A total of 174 consecutive patients who underwent robotic mitral valve surgery at our institution between May 2011 and March 2017 were reviewed for this study. Of these, 40 patients were ventilated using MVV. In this study, the effect of MVV on postoperative pulmonary function is evaluated. Therefore, in order to reduce the presumable confounding effect of early reoperations and sternotomy conversions on the analysis, patients who underwent conversion to open sternotomy or thoracotomy or were reoperated during the first postoperative 24 hours due to surgical complications were excluded from the study (7/40 (17.5%) and 21/134 (15.4%) patients with MVV and standard treatment, respectively ($p = 0.808$)). The preoperative characteristics of the 146 patients who met the inclusion criteria are presented in Table 1, including 33 patients who were ventilated using the minimal ventilation method and 113 patients who were treated in the standard fashion and disconnected from the ventilator during CPB.

To reduce selection bias, PSM in a 2:1 ratio was employed using 11 pre-selected variables that included risk factors for UPE and for prolonged ventilation reported in recent studies.[10,13] PSM resulted in two well-matched study groups of 31 and 54 patients in the minimal ventilation and the standard ventilation groups, respectively. The patient flow diagram is presented in Figure 1.

Postoperative PaO_2/FiO_2 ratios and arterial lactate levels were assessed to evaluate postoperative pulmonary function. The chest radiographs from the first postoperative day were evaluated by a radiologist (N.L.). UPE was defined as unilateral pulmonary edema of the right lung, where at least 25% of the right hemithorax was opacified and showed either interstitial thickening indicating interstitial edema or air bronchograms and consolidation indicating alveolar edema.

This study was approved by the local institutional board and the local ethics committee.

Operative technique and perioperative care

All operations were performed using the da Vinci® Si Surgical system (Intuitive Surgical, Sunnyvale, CA, USA). The service port and the ports for the endoscope and the robotic arms were placed in the right intercostal spaces. The right femoral artery was cannulated with a 21- or 23-Fr arterial cannula (EndoReturn™, Edwards Lifesciences, Irvine, CA, USA), and bicaval venous cannulation was established via right femoral and jugular veins. Bipolar intracardiac pacemaker was administered via the right subclavian vein, and a Swan–Ganz catheter was applied when necessary. In the first operations, antegrade cold crystalloid cardioplegia was used alone. In the later operations, retrograde cardioplegia was also delivered using a coronary sinus catheter (ProPlege™, Edwards Lifesciences), cardioplegia solution was changed to intermittent cold blood cardioplegia, and perfusion temperature was lowered to 32°C to ensure adequate myocardial protection. Aortic occlusion was performed primarily with an endoaortic balloon (EndoClamp™ or IntraClude™, Edwards Lifesciences), but the Chitwood

Table 1. Demographic data prior to propensity score matching.

Demographic data	Minimal ventilation (n = 33)	Standard treatment (n = 113)	p value	Standardized difference
Male[a]	26 (78.8)	90 (79.6)	1.000	0.02
Age[a] (years)	57.3 (13.6)	59.5 (10.6)	0.338	0.18
BSA[a] (m^2)	1.99 (0.26)	1.98 (0.20)	0.881	0.04
GFR[a] (mL/min)	96 (35)	94 (28)	0.676	0.06
Pulmonary hypertension[a]			0.110	
Normal	20 (60.6)	46 (40.7)		0.41
Moderate	9 (27.3)	52 (46.0)		0.40
Severe	4 (12.1)	15 (13.3)		0.03
Atrial fibrillation[a]	14 (42.4)	32 (28.3)	0.140	0.30
Ejection fraction[a]			1.000	
>50%	31 (93.9)	105 (92.9)		0.04
⩽50%	2 (6.1)	8 (7.1)		0.04
NYHA[a]			0.124	
I	7 (21.2)	15 (13.3)		0.21
II	17 (51.5)	50 (44.2)		0.15
III	7 (21.2)	46 (40.7)		0.43
IV	2 (6.1)	2 (1.8)		0.22
Diabetes[a]			0.261	
No diabetes	30 (90.9)	110 (97.3)		0.21
Non-insulin dependent	1 (3.0)	1 (0.9)		0.11
Insulin dependent	2 (6.1)	2 (1.8)		0.17
Smoking[a]			0.618	
No smoking	27 (81.8)	84 (74.3)		0.28
Ex-smoker	4 (12.1)	22 (19.5)		0.20
Current smoker	2 (6.1)	7 (6.2)		0.01
COPD	0	0	1.000	
Asthma	1 (3.0)	4 (3.5)	1.000	
Hypertension	11 (33.3)	36 (31.9)	1.000	
Stroke	1 (3.0)	1 (0.9)	1.000	
TIA	1 (3.0)	0	1.000	
EuroSCORE I	2.08 (1.51-3.13)	1.96 (1.51-2.71)	0.821	
Degenerative mitral valve disease	33 (100)	113 (100)	1.000	
Mitral valve leaflet pathology			0.417	
Isolated posterior leaflet	24 (72.7)	92 (82.1)		
Isolated anterior leaflet	4 (12.1)	11 (9.8)		
Bileaflet	5 (15.2)	9 (8.0)		

BSA: body surface area; GFR: glomerular filtration rate; NYHA: New York Heart Association; COPD: chronic obstructive pulmonary disease; TIA: transient ischemic attack; EuroSCORE: European System for Cardiac Operative Risk Evaluation.
Data shown as number of patients (%) or mean ± SD (range) or median (interquartile range).
[a]Variables included in propensity score matching.

clamp was used in some operations. The endoaortic balloon was placed under echocardiographic guidance during rapid ventricular pacing. If ventricular pacing was not functioning, an intravenous adenosine bolus was administered.

Anesthesia

Anesthesia was induced with propofol or etomidate, fentanyl, and rocurone and maintained with sevoflurane and opioid (fentanyl, alfentanil, or sufentanil). Inotropic or vasoconstrictive medications were administered when needed. Intravenous cefuroxime and vancomycin were routinely administered at induction. Patients were intubated using a double-lumen endotracheal tube to allow OLV. The double-lumen endotracheal tube was exchanged for a standard endotracheal tube postoperatively in the operating room.

Ventilation and extubation

When the operation started, OLV of the left lung was instituted and the right lung was allowed to collapse, and all patients were disconnected from the ventilator when CPB started. In the minimal ventilation group,

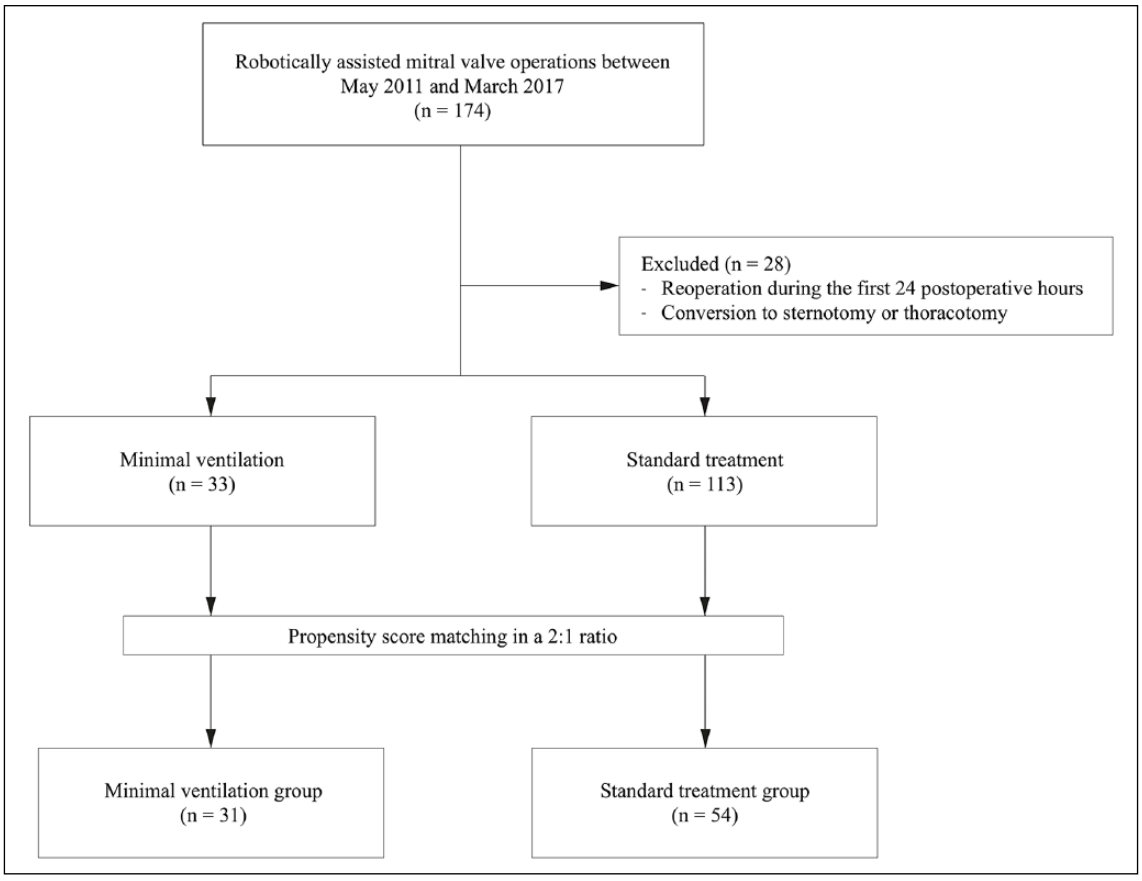

Figure 1. Patient flow diagram.

minimal ventilation of both lungs (tidal volume: 50-80 mL, respiratory rate: 6-8/min, FiO_2: 25-35%, PEEP: 0) was started after aortic occlusion and continued throughout CPB. In the standard treatment group, patients were kept disconnected from the ventilator during CPB.

The extubation criteria are listed in Table 2. These criteria are used for both conventional sternotomy operations and for robotically assisted or minimally invasive thoracoscopic operations. These criteria have been unchanged during our robotic program between the years 2011 and 2017.

Table 2. Extubation criteria after robotically assisted mitral valve surgery.

Patient responds adequately to verbal stimuli
Stable hemodynamics
Normothermia
No active bleeding
$FiO_2 < 40\%$
$EtCO_2$ between 4.5 and 5.5 kPa
$PaO_2 > 10$ kPa
$PaCO_2$ between 4.5 and 5.5 kPa or at the preoperative level
pH between 7.35 and 7.42
Respiratory rate of mechanical ventilation < 2/min
Patient's own respiratory rate < 20/min
PEEP < 6 cmH_2O

FiO_2: fraction of inspired oxygen; $EtCO_2$: end-tidal carbon dioxide; PaO_2: arterial partial pressure of oxygen; $PaCO_2$: arterial partial pressure of carbon dioxide; PEEP: positive end-expiratory pressure.

Statistical analysis and PSM

IBM SPSS® version 24.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis and data collection. Kolmogorov–Smirnov test was performed to test the normality of the continuous variables. Nominal values are reported as counts and percentages, and continuous variables are reported as median and interquartile range (IQR) or as mean and standard deviation. The Mann–Whitney U-test or the independent samples T-test was used to test the differences of the continuous variables between the study groups, and Chi-square or Fisher's exact test was used to test the differences of the categorical variables. The α-level was set at 0.05 for statistical significance.

PSM was employed to reduce selection bias and to balance the two study groups with respect to covariates that might affect the postoperative clinical course and outcomes of the ventilation-related parameters. The covariates that were included in the propensity score

Table 3. Operative data prior to propensity score matching.

Operative data	Minimal ventilation (n = 33)	Standard treatment (n = 113)	p value	Standardized difference
CPB time[a] (min)	148 (127–166)	154 (135–177)	0.205	0.25
Cross-clamp time (min)	102 (87–124)	105 (90–125)	0.470	
Console time (min)	125 (107–145)	130 (112–157)	0.319	
Operation length (min)	247 (221–270)	248 (225–278)	0.748	
Concomitant surgery				
TVP	1 (3.0)	4 (3.5)	1.000	
AF ablation	10 (30.3)	23 (20.4)	0.243	
Myxoma resection	1 (3.0)	0	1.000	
Mitral valve repair	33 (100)	112 (99.1)	1.000	
Isolated neochord implantation	18 (54.5)	49 (43.8)	0.323	
Isolated leaflet resection	7 (21.2)	43 (38.4)	0.095	
Neochord and resection	5 (15.2)	6 (5.4)	0.126	
Commissuroplasty or cleft closure	3 (9.1)	10 (8.9)	1.000	
Isolated annuloplasty	0	2 (1.8)	1.000	

CPB: cardiopulmonary bypass; TVP: tricuspid valve repair; AF: atrial fibrillation.
Data shown as number of patients (%) or mean ± SD (range) or median (interquartile range).
[a]Variables included in propensity score matching.

analysis are presented in Tables 1 and 3 and included patient age, sex, body surface area (BSA), smoking status, glomerular filtration rate (GFR), pulmonary artery systolic pressure, atrial fibrillation (AF), New York Heart Association (NYHA) class, ejection fraction (EF), diabetes, and CPB time. These covariates were preselected and included potential risk factors for UPE and prolonged ventilation. Altogether, 146 patients were included in the PSM, with 33 patients who were ventilated using MVV and 113 patients who were ventilated using the standard method during CPB. The inclusion of CPB time in the PSM aimed to match the right lung collapse time between the groups. In addition, matching of CPB time between the groups was considered to reduce the confounding effect of the learning curve of a robotic cardiac surgery program, which is associated with longer operative times during the first operations.[31]

PSM was performed in a 2:1 ratio to ensure an adequate number of study patients. Matching was conducted without replacement using the nearest neighbor algorithm with a 0.3 caliper resulting in two well-matched study groups of 31 and 54 patients in the minimal and standard ventilation groups, respectively. PSM was also tested using the greedy algorithm in a 2:1 ratio. The greedy algorithm resulted in a larger number of matched patients (33 and 66 patients in the minimal ventilation and standard treatment groups, respectively), but the standardized differences of the PSM covariates between the study groups were not within acceptable limits. We therefore considered caliper matching superior to the greedy matching algorithm, resulting in two study groups of 31 and 54 patients in the MVV and standard treatment groups, respectively. The resulting standardized differences of the covariates that were included in the PSM are presented in Tables 4 and 5. A standardized difference of $\leqslant 0.1$ was considered a good match. In our data, the only variables with a standardized difference >0.1 were preoperative NYHA IV class and preoperative diabetes status. NYHA IV heart failure symptoms were more common in the minimal ventilation group as there were 2 (6.5%) versus 2 (3.7%) patients in the minimal ventilation and the standard treatment groups, respectively, with a standardized difference of 0.13. Similarly, the rate of insulin-dependent diabetes was higher among patients in the minimal ventilation group with 2 (6.5%) versus 2 (3.7%) patients in the minimal and standard treatment groups, respectively, with a standardized difference of 0.13. These minor imbalances were considered acceptable.

Due to unequal time points of postoperative PaO_2/FiO_2 and arterial lactate level measurements among study patients, PaO_2/FiO_2 curves of the first 5 hours and arterial lactate curves of the first 15 postoperative hours were constructed for individual study patients. The areas under the curves standardized by the length of the follow-up were calculated to compare the two study groups.[32]

Results

The postoperative ventilation parameters, blood gas measurements, and complications are reported in Table 6. Patients in the minimal ventilation group had shorter total ventilation times than patients in the standard treatment group, 12.0 (IQR: 9.9-15.0) versus 14.0 (IQR: 12.0-16.3) hours, respectively ($p = 0.036$). In addition, the arterial lactate levels were significantly lower in the MVV group, 0.99 (IQR: 0.81-1.39) versus 1.28 (IQR: 0.99-1.86) mmol/L ($p = 0.01$). The postoperative

Table 4. Demographic data after propensity score matching.

Demographic data	Minimal ventilation (n = 31)	Standard treatment (n = 54)	p value	Standardized difference
Male[a]	24 (77.4)	43 (79.6)	0.791	0.05
Age[a] (years)	57.1 (13.9)	57.6 (10.0)	0.851	0.04
BSA[a] (m^2)	1.98 (0.27)	1.99 (0.21)	0.929	0.02
GFR[a] (mL/min)	92 (64–118)	89 (80–116)	0.596	0.02
Pulmonary hypertension[a]			0.998	
Normal	18 (58.1)	31 (57.4)		0.01
Moderate	9 (29.0)	16 (29.6)		0.01
Severe	4 (12.9)	7 (13.0)		0.00
Atrial fibrillation[a]	13 (41.9)	22 (40.7)	1.000	0.02
Ejection fraction[a]			1.000	
>50%	29 (93.5)	49 (90.7)		0.10
⩽50%	2 (6.5)	5 (9.3)		0.10
NYHA[a]			0.944	
I	6 (19.4)	10 (18.5)		0.02
II	16 (51.6)	30 (55.6)		0.08
III	7 (22.6)	12 (22.2)		0.01
IV	2 (6.5)	2 (3.7)		0.13
Diabetes[a]			0.775	
No diabetes	28 (90.3)	51 (94.4)		0.16
Non-insulin dependent	1 (3.2)	1 (1.9)		0.09
Insulin dependent	2 (6.5)	2 (3.7)		0.13
Smoking[a]			0.961	
No smoking	25 (80.6)	44 (79.6)		0.02
Ex-smoker	4 (12.9)	8 (14.8)		0.06
Current smoker	2 (6.5)	3 (5.6)		0.04
COPD	0	0	1.000	
Asthma	1 (3.2)	0	0.365	
Hypertension	11 (35.5)	21 (38.9)	0.819	
Previous stroke	0	1 (1.9)	1.000	
TIA	1 (3.2)	0	1.000	
EuroSCORE I	2.08 (1.51–3.19)	1.72 (1.51–2.14)	0.255	
Degenerative mitral valve disease	31 (100)	54 (100)	1.000	
Mitral valve leaflet pathology			0.300	
Isolated posterior leaflet	22 (71.0)	45 (83.3)		
Isolated anterior leaflet	4 (12.9)	4 (7.4)		
Bileaflet	5 (16.1)	4 (7.4)		

BSA: body surface area; GFR: glomerular filtration rate; NYHA: New York Heart Association; COPD: chronic obstructive pulmonary disease; TIA: transient ischemic attack; EuroSCORE: European System for Cardiac Operative Risk Evaluation.
Data shown as number of patients (%) or mean ± SD (range) or median (interquartile range).
[a]Variables included in propensity score matching.

PaO_2/FiO_2 level, intensive care unit stay, and hospitalization length were similar in both groups.

There was no difference in the rate of postoperative infections between the two study groups. One patient in the standard ventilation group had catheter-related sepsis, and one patient in the minimal ventilation group had postoperative empyema. The rate of pneumonia was similar between the study groups (3.2% and 1.9% patients in the minimal and standard treatment groups, respectively, p = 1.000). The rate of postoperative non-infectious complications in both study groups was low. Two (6.5%) patients in the minimal ventilation group and four patients (7.4%) in the standard treatment group had UPE postoperatively (p = 1.000). One patient in the minimal ventilation group had a transient ischemic attack postoperatively. There were no other significant complications among patients included in this study.

Discussion

In an attempt to reduce the risk of postoperative pulmonary dysfunction and postoperative UPE, 40 of 174 patients undergoing robotically assisted mitral valve

Table 5. Operative data after propensity score matching.

Operative data	Minimal ventilation (n = 31)	Standard treatment (n = 54)	p value	Standardized difference
CPB time[a] (min)	152 (33)	152 (34)	0.997	0.00
Cross-clamp time (min)	104 (28)	105 (26)	0.860	
Console time (min)	131 (33)	132 (33)	0.942	
Operation length (min)	251 (40)	245 (41)	0.588	
Concomitant surgery				
TVP	1 (3.2)	3 (5.6)	1.000	
AF ablation	9 (29.0)	12 (22.2)	0.602	
Myxoma resection	0	0	1.000	
Mitral valve repair	31 (100)	54 (100)		
Isolated neochord implantation	17 (54.8)	23 (42.6)	0.367	
Isolated leaflet resection	7 (22.6)	20 (37.0)	0.228	
Neochord + resection	5 (16.1)	3 (5.6)	0.134	
Commissuroplasty or cleft closure	2 (6.5)	5 (9.3)	1.000	
Isolated annuloplasty	0	2 (3.7)	0.531	

CPB: cardiopulmonary bypass; TVP: tricuspid valve repair; AF: atrial fibrillation.
Data shown as number of patients (%) or mean ± SD (range) or median (interquartile range).
[a]Variables included in propensity score matching.

Table 6. Outcomes and complications.

	Minimal ventilation (n = 31)	Standard treatment (n = 54)	p value
Outcomes			
Total ventilation time (hours)	12.0 (9.9–15.0)	14.0 (12.0–16.3)	0.036
ICU stay (days)	1.0 (1.0–1.0)	1.0 (1.0–1.0)	0.460
Hospitalization time (days)	7 (6–8)	7 (6–8)	0.774
Postoperative PaO_2/FiO_2 (mmHg)	314 (94)	312 (107)	0.912
Postoperative arterial lactate (mmol/L)	0.99 (0.81–1.39)	1.28 (0.99–1.86)	0.010
Complications			
30-day mortality	0	0	1.000
Unilateral pulmonary edema	2 (6.5)	4 (7.4)	1.000
TIA	1 (3.2)	0	0.365
Dialysis	0	0	1.000
Myocardial infarction	0	0	1.000
Stroke	0	0	1.000
Second pump run	1 (3.2)	1 (1.9)	1.000
Pacemaker implantation	1 (3.2)	1 (1.9)	1.000
Low output syndrome or ECMO	0	0	1.000
IABP	0	0	1.000
Sepsis	0	1 (1.9)	1.000
Pneumonia	1 (3.2)	1 (1.9)	1.000
Empyema	1 (3.2)	0	0.365
Wound infection	0	0	1.000

ICU: intensive care unit; PaO_2: arterial partial pressure of oxygen; FiO_2: fraction of inspired oxygen; TIA: transient ischemic attack; ECMO: extracorporeal membrane oxygenation; IABP: intra-aortic balloon pump.
Data shown as number of patients (%) or mean ± SD (range) or median (interquartile range).

surgery were ventilated with a small tidal volume during CPB. In our standard practice, patients are disconnected from the ventilator during CPB. The effect of MVV on postoperative ventilation-related parameters and morbidity was assessed in this study. Patients who were ventilated using MVV had shorter ventilation times in comparison to patients who were not ventilated during CPB. In addition, postoperative lactate levels were lower among patients in the minimal ventilation group, suggesting better perfusion of the lungs during surgery.[19,21] The minimal ventilation method did not have any effect on postoperative PaO_2/FiO_2 levels, intensive care unit

stay, or hospitalization length. Two (6.5%) patients in the minimal ventilation group and four (7.4%) patients in the standard ventilation group developed UPE, and this difference was not statistically significant.

In thoracic surgery, the use of CPAP or HFJV to the collapsed lung during OLV has been evaluated with improved oxygenation, reduced pulmonary shunting, and lower local inflammatory response of the affected lung.[24–28] In studies assessing HFJV during OLV, HFJV has improved respiratory parameters even though tidal volumes generated by HFJV are smaller than the anatomic dead space.[27,28,33] In cardiac surgery with the sternotomy approach, the effects of CPAP and mechanical ventilation during CPB on postoperative oxygenation and pulmonary dysfunction have been varying, with some results suggesting that CPAP may improve postoperative oxygenation without any effect on clinical outcomes.[22,23] In our series of minimally invasive and robotically assisted mitral valve operations, the use of CPAP or PEEP to the collapsed lung was not considered feasible due to the resulting limited visibility to the operative field. Instead, both lungs were ventilated without PEEP and with a tidal volume of 50-80 mL, which did not affect the surgical exposure of the heart. In contrast to the studies evaluating the effect of different ventilation methods on respiratory parameters during OLV, the operations in our series were performed using CPB, and therefore, the impact of MVV on intraoperative oxygenation was not evaluated. The aim of MVV was to reduce intraoperative lung hypoperfusion and subsequently reduce postoperative pulmonary dysfunction. Small tidal volumes were hypothesized to recruit alveoli and reduce hypoxic pulmonary vasoconstriction to allow blood flow to otherwise hypoperfused lung parenchyma during CPB. The lower postoperative lactate levels among MVV patients support this hypothesis.

This is a retrospective study with a relatively small number of study patients. Even though PSM resulted in two well-matched study groups of patients with either minimal ventilation or standard treatment, the effect of selection bias cannot be fully eliminated. The decision to use the minimal ventilation strategy for an individual patient was based on anesthesiologist preference and was not driven by patient characteristics. Patients were therefore not selected for minimal ventilation. After PSM, patients with NYHA IV heart failure symptoms and patients with insulin-dependent diabetes were slightly more common in the minimal ventilation group with respect to the standardized differences between the groups. This difference might favor the standard treatment group and reduce the observed positive effects in the minimal ventilation group.

The main result of this study is that ventilation time was shorter among patients who were ventilated using the minimal ventilation method. In our practice, the extubation criteria of patients operated using robotic assistance have been the same during the whole robotic surgical program from 2011 to 2017. Despite the clear institutional extubation criteria, the final decision of when a patient is extubated is subjective and specialist dependent. However, intensive care personnel were not aware of the ventilation method used during CPB, and therefore, the impact of these confounding factors is assumed to be minimal. There may also be unrecognized factors that have an impact on the reported results.

To our knowledge, this is the first study that evaluates the effect of MVV on postoperative oxygenation and clinical recovery after robotically assisted mitral valve surgery. Postoperative lactate levels were lower among patients in the MVV group, suggesting better lung perfusion during surgery.[19,21] In addition, total ventilation times were shorter among patients in the MVV group, but the differences were in fact small, and further studies are required to confirm the possible advantages of the MVV method in robotically assisted cardiac surgery.

Declaration of Conflicting Interests

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