LUNG-PROTECTIVE VENTILATION IN ONE-LUNG VENTILATION FOR CHILDREN UNDERGOING MINIMALLY INVASIVE VENTRICULAR SEPTAL DEFECT SURGERY: EFFECTS ON HEMODYNAMIC

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A prospective cohort study was conducted on 63 pediatric patients with congenital VSD was conducted to describe hemodynamic changes and adverse effects of protective lung ventilation (PLV) during one-lung ventilation (OLV) in minimally invasive ventricular septal defect (VSD) surgery. 63 pediatric patients with congenital VSD were randomly assigned into two groups: conventional lung ventilation (CLV) and protective lung ventilation (PLV), from June 2023 to December 2024 at the Vietnam National Children's Hospital. Data collected included patient characteristics, anatomical lesions, surgical details, mechanical ventilation parameters, hemodynamic and blood gas monitoring during and after surgery, ventilation duration, and respiratory complications. Comparison was made between heart rate, mean blood and central venous pressure at different timelines. Statistical methods included t-tests, Chi-square, regression analysis, using Jamovi 2.6.24 software. Children diagnosed with congenital VSD underwent minimally invasive open-heart surgery via right mini-thoracotomy. 29 received CLV, and 34 received PLV. Mean age: 26.6 ± 20.6 months old. Mean weight: 11 ± 4kg. Cardiopulmonary bypass time: 67.9 ± 15.3 mins. Aortic cross-clamp time: 46.2 ± 12.1 mins. 10 patients were extubated in the operating room Postoperative ventilation time: average 5.2 hours. No organ failure or major hemodynamic instability occured. Protective lung ventilation is safe during anesthesia and resuscitation for minimally invasive VSD repair in children, with no major circulatory or hemodynamic complication.

Keywords: One lung ventilation, Lung protective ventilation strategy, minimally invasive cardiac surgery.

I. INTRODUCTION

Lung protection should begin early when initiating positive pressure ventilation. Even short-term intraoperative ventilation in patients without pre-existing lung disease can negatively impact respiratory function and cause postoperative complications. Patient underwent minimal invasive cardiac surgery had a strong relative indication for OLV as this technique help surgeon better exposure of surgical field and benefits patients in reduced bypass time.[1,2] Also, for pediatric population, using bronchial blocker to isolated lung had been proved to be associated with lower risk of hypoxemia.[3] In adults undergoing OLV, lung-protective strategies reduce pulmonary inflammation and complications.[4-6] For minimally invasive valve surgery in adults, lower tidal volumes improve outcomes.[7] However, there is no standardized guideline for LPV in anesthetized patients requiring OLV, and practices vary widely among anesthesiologists. Nevertheless, there is a general consensus on the importance

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of LPV during thoracic surgery.[8,9] There is limited research worldwide on LPV in children with congenital heart disease requiring OLV for minimally invasive heart surgery. There are theoretical concerns regarding low tidal volume's effect on hemodynamics associated with atelectasis, hypoxemia and intrapulmonary shunt. Therefore, this study was conducted to evaluate LPV's impact on hemodynamic function and investgate adverse effects in children undergoing minimally invasive VSD repair.

II. MATERIALS AND METHODS

1. Subjects

Children aged 6 months to 6 years old with congenital VSD scheduled for minimally invasive open heart surgery via right thoracotomy.

2. Methods

Study Design: A prospective cohort with two randomized groups: CLV and PLV. All the patients who fulfilled the inclusion criteria were recruited. A bronchial blocker was introduced into the right lung of patients who were under general anesthesia. When the tip of blocker was at the desired position, the blocker would be deflated and pushed 2cm further into the lung. Patients remain 2 lungs ventilation at all time. Then, the patient was placed in the left lateral position and OLV phase started just before the surgeon open the pleural cavity. After wean off bypass, patients remained OLV until recruitment aveolar and back to two lung ventilation. The CLV group had tidal volume setting at 6 ml/kg during OLV and 10 ml/kg during 2 lungs ventilation, while the PLV group had tidal volume setting at 4 ml/kg during OLV and 8 ml/kg during 2 lungs ventilation. Both groups had the same PEEP of 5cmH_2O and adhere to the same protocol for anesthesia management for children undergoing VSD repair at the Heart Center, National Children's Hospital.

Data Collection and Analysis: Collected variables: patient characteristics, VSD features, surgical details, intraoperative clinical and mechanical parameters, postoperative outcomes. Data were collected at different timelines:

- T0 Post-induction
- T1 after putting on lateral position, before one-lung
- T2 After one-lung ventilation 10m
- T3 After one-lung ventilation 30m
- T4 After bypass and ventilation again
- T5 After MUF and aveolar recruitement
- T6 After putting on supine
- T7 In the first 6h in CICU
- T8 In the first 12h in CICU

Statistical methods

Descriptive variables: frequency, percentage, mean, SD.

Category variables: t-test, Chi-square, Pearson correlation, univariate and multivariate regression. Software: Jamovi 2.6.24. Significance level: $p < 0.05$.

3. Research ethics

Approved by the National Children's Hospital Ethics Committee(IRB- VN01037/IRB00011976/FWA00028418 issued date 10th July 2023). Informed consent obtained.

III. RESULTS

63 patients (43 males , 20 females) underwent right mini-thoracotomy VSD repair. 29 were in the CLV group, 34 in the PLV group.

There was no significant difference in patient characteristics, VSD lesions as well as intraoperative progress between the two study groups; although interms of gender distribution, the PLV group has more males than the CLV group.

Table 1. Patients' characteristics

Variables (Mean (SD))	CLV group	PLV group	Total
Age (months)	24.8 (15.6)	28.1 (24.2)	26.6 (20.6)
Gender (Male:Female)	16:13	27:7	43:20
Weighed (kg)	10.5 (3.3)	11.4 (4.5)	11.0 (4.0) Min - Max 5.4 - 21.0
VSD lesions			
Average VSD Size (mm)	7.2 (1.9)	7.06 (2.7)	7.1 (2.4)
Pressure Gradient (mmHg)	65.8 (23.4)	61.5 (25.6)	63.4 (24.5)
EF pre-op (%)	63.5 (5.9)	64.9 (5.9)	64.3 (5.9)
Surgical progress			
Operation time (hours)	3.8 (0.5)	3.7 (0.5)	3.7 (0.5)
Bypass time (minutes)	69.0 (17.4)	66.9 (13.5)	67.9 (15.3)
Cross-clamp time (minutes)	47.2 (14.9)	45.3 (11.5)	46.2 (13.1)
One-lung ventialtion time (minutes)	31.5 (9.0)	34.1 (8.3)	32.9 (8.7)
Fentanyl intra-op (mcg/kg/h)	3.5 (2.1)	4.2 (2.2)	3.9 (2.2)
Rocuronium intra-op (mg/kg/h)	0.6 (0.4)	0.7 (0.2)	0.7 (0.3)
Postoperative period			
Postoperative mechanical ventilation time (hours)	5.6 (4.4)	4.9 (4.7)	5.2 (4.6)

There were 10 patients who were extubated and recovered in the operating room, and 50% of the patients had a mechanical ventilation time ≤ 4 hours postoperative. The longest postoperative mechanical ventilation time is up to 21 hours due to pneumonia.

There were 5 cases of residual VSD lesion, diameter ≤ 1.9mm and no indication for reintervention, one case with mild obstruction of the left ventricular outlet, one case with a mild aortic valve regurgitation, one case developed seizures after extubation – CT finding was subdural hematoma of unknown cause and treated conservatively.

Comparing T1 with T0 there was a decrease in heart rate and mean IBP, other times the heart rate increased statistically. The reason for the decrease may be due to the effect of paravertebral block performed at the time of T1.

Table 2. Hemodynamics parameter

Timeline / Parameter	T0 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)	T4 Mean (SD)	T5 Mean (SD)	T6 Mean (SD)
HR (bpm)	111.0 (18.5)	106.5 (15.3)	117.5 (18.5)	127.2 (16.3)	123.0 (16.6)	118.0 (14.4)	120.7 (14.5)
PVC (mmHg)	7.8 (1.6)	8.8 (2.1)	9.1 (2.7)	9.7 (2.4)	8.6 (3.0)	7.9 (2.3)	7.8 (2.1)
Mean IBP (mmHg)	68.6 (9.6)	65.4 (9.2)	59.8 (9.2)	58.8 (9.4)	59.8 (9.4)	68.0 (9.1)	70.8 (7.8)

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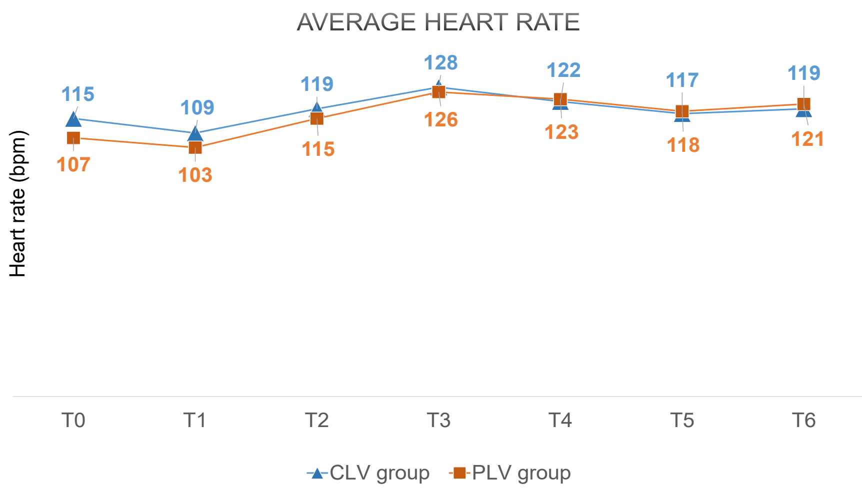

Chart 1. Changes in heart rate at different times between 2 groups

There was no difference in heart rate between the two groups at the different perioperative time.

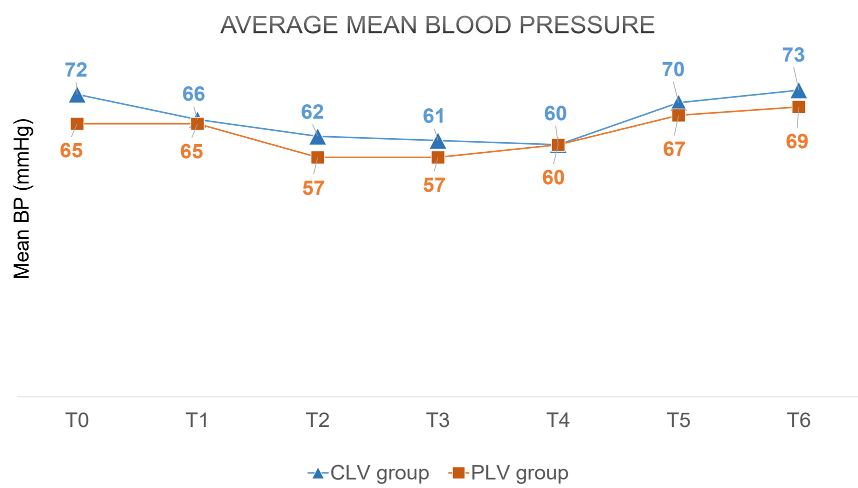

Chart 2. Change in mean IBP between 2 groups

There was no difference in mean blood pressure between the two groups at T1, T4, T5. However, the mean blood pressure of the PLV group was significantly lower at the time of T0 after induction ($p < 0.001$) and T2 after 10 minutes of one-lung ventilation ($p = 0.024$).

Table 3. Comparison between T1 vs T0 and T2 vs T0

Variables	T0 Mean (SD)	T1 Mean (SD)	p (T1 vs T0)	T2 Mean (SD)	p (T2 vs T0)
Heart Rate (bpm)	111.0 (18.5)	117.5 (18.5)	0.002	127.2 (16.3)	< 0.001
PVC (mmHg)	7.8 (1.6)	9.1 (2.8)	< 0.001	9.7 (2.4)	< 0.001
Mean BP (mmHg)	68.6 (9.6)	59.8 (9.2)	< 0.001	58.8 (9.4)	< 0.001
Saturation (%)	99.8 (0.7)	96.5 (3.1)	< 0.001	96.1 (3.2)	< 0.001
$etCO_2$ (mmHg)	34.3 (5.0)	40.9 (5.9)	< 0.001	43.4 (7.3)	< 0.001
Lactate (mmol/L)	0.7 (0.3)	0.6 (0.3)	< 0.001	0.5 (0.3)	< 0.001

There were significant changes in some hemodynamic variables on lateral position and implementing OLV for ten minutes, although these changes were within clinical tolerance and need no extra intervention such as fluid resuscitation or start using inotrope.

IV. DISCUSSION

The patients in our study had a lower mean age than some other studies of right thoracotomy for VSD, such as Selim Aydin's group, which had a mean age of 16 months old (between 4 and 84 months old).[10] There were no death, no caseof having to re-bypass or having to transfer to midline incision, and no major complication occurred during the follow-up. There are 5 cases of very small residual VSD, the size of the residual shunt is up to 1.9mm, representing 7.9%. This rate is higher than 1/24 of the Selim authors.[10] This rate is also higher than the 2022 study of 472 patients with open heart closure of VSD by Jiaquan Zhu et al., who reported 3 cases of having to restart the machine due to residual lesion, and 1 case of detached patch had to be re-operated. This may be because Zhu and his colleagues chose different minimally invasive approaches to access each different VSD sites, making it better to exposure and manage the lesion.[11] When comparing minimal right thoracotomy and midline incision for children weighing < 5kg, authors Gang Li and colleagues showed shorter operation time, less amount of drainage, and less blood transfusion for the right thoracotomy group, while the parameter of peak airway pressures, oxygen saturation and partial carbon pressure are the same between the two groups.[12]

One-lung ventilation (OLV) can affect hemodynamic such as create right-left shunt in the lungs. The loss of ventilation in one lung leads to the collapse of that lung, causing a right-left shunt in the lungs, which reduces arterial blood oxygen. Positive end-expiratory pressure (PEEP) can help expand the lungs and reduce the flow through shunt but can have a negative impact if setting PEEP is too high. There are also contribution of pulmonary arterial hypertension and right heart failure. Pulmonary vasoconstriction due to hypoxia increases pulmonary vascular resistance (PVR), leading to increased right ventricular afterload. Moreover, hypercoagulation and hemodynamic fluctuation as nature of CPB cause adverse effects too. One-lung ventilation can lead to hypercapnia, stimulate pulmonary vasoconstriction, increase right ventricular load, and can cause arrhythmias. This may explain the changes in blood vessels and blood pressure during surgery.

Applying low tidal volume during OLV with VT set to 4-5 ml/kg had been proven to shorten the length of hospital stay, decreased the risk of acute lung injury, improved oxygenation andventilation-perfusion mismatch, meanwhile did not impact the risk of atelectasis.[13] However, the results were not consistent among studies and it was even more difficult to measure the impact of tidal volume setting on hemodynamic in congenital open heart surgery, whereas the fluctuation in pressure and resistance were inevitable. In our study, we failed to detect a significant difference in some basic hemodynamic variables between two groups. Postoperatively, in cardiac intensive care unit, there was no organ failure nor severely hemodynamic undesired consequences.

V. CONCLUSION

From preliminary results, we found that using low tidal volume setting inlung-protective strategy during anesthesia and resuscitation for minimally invasive VSD repair in children was safe as there was no significant hemodynamic or circulatory complication.

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