Original Article

Impact of bridging veno-venous extracorporeal membrane oxygenation to COVID-19 lung transplantation

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Background: Veno-venous extracorporeal membrane oxygenation (VV-ECMO) therapy is being increasingly used as respiratory support for patients with severe coronavirus disease 2019 (COVID-19)-associated acute respiratory distress syndrome (ARDS). However, the long-term outcome of VV-ECMO as a bridge to lung transplantation in COVID-19-associated ARDS remains unclear, hence the purpose of this study aimed to evaluate its long-term outcome, safety, and feasibility.

Methods: This was a retrospective cohort study from an institutional lung transplantation database between June 2020 and June 2022. Data on demographics, pre-transplantation laboratory values, postoperative outcomes, preoperative and postoperative transthoracic echocardiography findings, and survival rates were collected. Chi-square, Mann-Whitney U, Student's t, Kaplan-Meier, and Wilcoxon signed-rank tests were used for analysis.

Results: Twenty-five patients with COVID-19-associated ARDS underwent lung transplant surgery with VV-ECMO bridge. Unfortunately, six patients with COVID-19-associated ARDS using VV-ECMO died while waiting for transplantation during the same study period. Patients with VV-ECMO bridge were a more severe cohort than 16 patients without VV-ECMO bridge (lung allocation score: 88.1 *vs.* 74.9, P<0.001). These patients had longer intensive care unit and hospital stays (P=0.03 and P=0.02, respectively) and a higher incidence of complications after lung transplantation. The one-year survival rate of patients with VV-ECMO bridge was lower than that of patients without (78.3% *vs.* 100.0%, P=0.06), but comparable to that of patients with other lung transplant indications (84.2%, P=0.95). Echocardiography showed a decrease in the right ventricular systolic pressure (P=0.01), confirming that lung transplantation improved right heart function.

Conclusions: Our findings suggest that VV-ECMO can be used to safely bridge patients with COVID-19 associated ARDS with right heart failure.

Keywords: Lung transplantation; extracorporeal membrane oxygenation (ECMO); coronavirus disease 2019 (COVID-19); acute respiratory distress syndrome (ARDS)

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Introduction

Lung transplantation is a potentially life-saving treatment for critically ill patients with coronavirus disease 2019 (COVID-19)-associated acute respiratory distress syndrome (ARDS) (1-4). Prior to the COVID-19 epidemic, lung transplantation for ARDS itself was limited, accounting for only 0.15% (39/25,541) of all lung transplants in the 14-year United Network for Organ Sharing registry data from 2005 to 2018 (5,6). We reported the feasibility of lung transplantation for patients with COVID19-associated ARDS (1,7,8), and lung transplantation for COVID19-associated ARDS has gradually become more common since the COVID-19 pandemic, and a limited number of institutions and national studies, including ours, have reported relatively favorable results (1,3,9). The introduction of extracorporeal membrane oxygenation (ECMO) as a life-saving measure has been reported to reduce mortality in patients with COVID-19-related ARDS when other conventional therapies are ineffective (10-12). Outcomes for COVID-19 and non-COVID-19 patients who are introduced to ECMO are almost equivalent (13). However, COVID-19 -associated ARDS has been reported to have a high incidence of severe right heart failure (RHF) due to increased pulmonary vascular resistance caused by pulmonary microcirculation dysfunction (14). Therefore, strategies to protect the right heart from ECMO initiation are in high demand.

Dual lumen, jugular to pulmonary artery cannulas are inserted percutaneously through the right internal jugular vein, and were originally developed as a right ventricular assist device. They can be used as a strategy for veno-venous (VV)-ECMO by adding an oxygenator to the circuit (15). Such cannulas have the advantage of offloading the right ventricle (RV) because the inflow is in the right atrium and the outflow lies within the main pulmonary artery. The increased use of such cannulas during the COVID-19 pandemic was a response to the increased incidence of RHF (16). Such a configuration is occasionally described as veno-pulmonary arterial ECMO, which is also essentially returning venous blood to the venous circulation and belongs to the same group as VV-ECMO. However, reports on the long-term outcomes of VV-ECMO as a bridge to lung transplantation in ARDS patients remain unclear. This study evaluated the safety and feasibility of VV-ECMO as a bridge to lung transplantation in patients with COVID-19-associated ARDS complicated with severe RHF.

Highlight box

Key findings

- Veno-venous extracorporeal membrane oxygenation (VV-ECMO) can be used to safely bridge patients with coronavirus disease 2019 (COVID-19)-associated acute respiratory distress syndrome (ARDS) with right heart failure (RHF).

What is known and what is new?

- VV-ECMO is being increasingly used as respiratory support for patients with severe COVID-19-associated ARDS. However, reports on the long-term results, safety, and feasibility of VV-ECMO as a bridge to lung transplantation in COVID-19-associated ARDS remain unclear.
- VV-ECMO was safely performed as respiratory support prior to lung transplantation without major complications, and the one-year survival rate for patients supported by VV-ECMO was comparable to that of patients with indications for transplantation other than COVID-19-associated ARDS. Echocardiographic findings showed improvement in postoperative right ventricular systolic pressure after lung transplantation.

What is the implication, and what should change now?

- Long-term VV-ECMO support may be a feasible and safe to lung transplantation in patients with COVID-19-associated ARDS complicated by severe RHF.

Methods

Study design

Patient data were collected retrospectively using electronic medical records and stored in a database at the Northwestern University Medical Center in Chicago, Illinois, USA. Adult patients who underwent lung transplantation with preoperative VV-ECMO for COVID-19-associated ARDS at our institution between June 2020 and June 2022 were included. Multiorgan transplant recipients were excluded from the study. Data on patient demographics, comorbidities, donor characteristics, preoperative laboratory values, intraoperative and postoperative outcomes, and transthoracic echocardiography (TTE) results were collected. The number of deaths and etiologies among patients on the waiting list during the study period was also investigated. Demographic characteristics and prognosis were compared in a group of COVID-19-associated ARDS patients who used VV-ECMO preoperatively and a group of the patients who did not use it preoperatively. Prognosis was also analyzed including patients who received lung transplantation for indications other than COVID-19-associated ARDS during the same study period. The study was approved by the Institutional Review Board

of Northwestern University (Nos. STU00207250 and STU00213616). The need for patient consent for data collection was waived by the institutional review board due to the retrospective nature of this study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Statistical analysis

Recipient and donor characteristics, preoperative laboratory values, and intra- and postoperative outcomes were compared between COVID-19-associated ARDS patients with and without preoperative VV-ECMO. The Mann-Whitney U test or Student's *t*-test was used to compare independent continuous variables between the groups. The chi-square test was used to compare categorical variables, which were reported as numbers and percentages. The Wilcoxon signed-rank test was used to compare pre- and postoperative TTE values. The Kaplan-Meier method was used to estimate survival, and the Wilcoxon signed-rank test was performed to compare survival between the groups. Statistical significance was set at $P<0.05$. EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan) and a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria) were used to perform all the analyses.

ECMO indication criteria

Prior to lung transplantation, all intubated patients were treated by a multidisciplinary team in accordance with the guidelines of the National Heart, Lung, and Blood Institute's ARDS Network (17). Indications for ECMO evaluation included refractory hypoxemia with PaO_2 less than 55 mmHg, pulse oximetry oxygen saturation less than 88%, and pH level less than 7.2. Patients were evaluated with lung-protective mechanical ventilation with a plateau pressure of less than 35 mmHg, neuromuscular blockade, and prone positioning, according to recommendations from the Extracorporeal Life Support Organization (18). The decision to initiate ECMO was made by a multidisciplinary team of pulmonologists, thoracic surgeons, ECMO specialists, and intensivists using teleconferencing lines.

Indications for transplantation in COVID-19-associated ARDS

ARDS was defined according to the Berlin Definition (19). All patients with COVID-19-associated ARDS were treated by a multidisciplinary team that included surgeons, infectious disease physicians, pulmonary and critical care physicians, and cardiologists over the entire duration of the illness before being considered for transplantation. A referral for lung transplantation was made when this multidisciplinary team concluded that there was no longitudinal evidence of lung recovery, at least 4 to 6 weeks after the onset of COVID-19-associated ARDS, which is consistent with our previous study (1,7,8). All patients with COVID-19-associated ARDS received pre-transplant rehabilitation during hospitalization, achieving sufficient truncal strength to sit upright and move all four limbs against gravity. The first patient in the COVID-19 cohort lacked decisional capacity and was unable to participate in the study. Lung transplant evaluation was performed according to the International Society for Heart and Lung Transplantation guidelines (20). The broad transplant criteria for patients with COVID-19-associated ARDS included people aged 70 years or younger, two consecutive lower respiratory fluid polymerase chain reaction tests negative for SARS-CoV-2, single organ failure, no evidence of irrecoverable brain damage, and a body mass index less than or equal to 35 kg/m^2.

VV-ECMO cannulation procedure

All patients with COVID-19-associated ARDS were supported with VV-ECMO using a 29 or 31 French dual lumen cannula. The cannula was percutaneously inserted via the right internal jugular vein. A Swan-Ganz pulmonary artery catheter was inserted and floated into the main pulmonary artery, which was used to facilitate guidewire placement into the main pulmonary artery. Next, the cannula was passed through the main pulmonary artery using the Seldinger technique. All procedures were performed by experienced thoracic surgeons in a hybrid operating room under transesophageal echocardiographic and fluoroscopic guidance. The cannula was connected to either a Cardiohelp™ (Getinge, Gothenburg, Sweden) or CentriMag™ (Abbott, Abbott Park, IL, USA) ECMO circuit.

Anticoagulation during VV-ECMO support

Patients did not receive continuous anticoagulation unless there was a specific indication, such as deep venous thrombosis or pulmonary embolism, and there was no monitoring of bleeding parameters, such as activated clotting time or activated partial thromboplastin time.

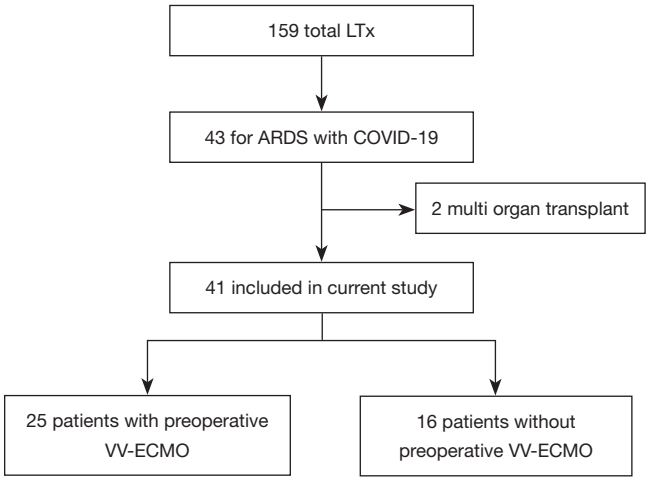

Figure 1 Study population of lung transplantation in patients with coronavirus disease 2019-associated acute respiratory distress syndrome with veno-venous extracorporeal membrane oxygenation bridge. LTx, lung transplantation; ARDS, acute respiratory distress syndrome; COVID-19, coronavirus disease 2019; VV-ECMO, veno-venous extracorporeal membrane oxygenation.

All patients who were not receiving continuous systemic anticoagulation received 5,000 unit of subcutaneous unfractionated heparin every 8 hours as a prophylactic dose to prevent deep venous thrombosis. VV-ECMO flow was maintained at a minimum of 3.0–3.5 L/min, consistent with our recent reports, to reduce thrombotic complications in the ECMO circuit (21-23).

Management of central venous catheters (CVCs)

CVCs were replaced every seven days, even if there were no signs of infection. New CVC replacements were performed in the same vein and not in a wire-based replacement, but in a different area or new vein. Weekly surveillance cultures for all ECMO patients were used to monitor bloodstream infections simultaneously.

Surgical technique

All surgeries were performed using clamshell incisions with or without ECMO. Patients received 5,000 units heparin as a single dose. Anticoagulation was not monitored by activated clotting time, and the heparin dose was not repeated during the surgery. Central VA-ECMO was used in all VA-ECMO cases. A VV-ECMO cannula was used for drainage in advance, and an outflow cannula [an 18-Fr EOPA cannula (Medtronic Bio-Console 560; Medtronic, Inc, Minneapolis, MN, USA)] was cannulated into the ascending aorta. After both lungs were implanted, the aortic cannula was removed and returned or decannulated VV-ECMO. To ensure perfusion to the first lung, the pulsatility of the systolic was maintained at 15–20 mmHg after the first lung was implanted (24,25).

Definition of complication and classification

Primary graft dysfunction (PGD)

PGD was defined based on the International Society for Heart Lung Transplantation (ISHLT) guideline (26), and graded by PaO_2/FiO_2 ratio as follows: Grade 1: PaO_2/FiO_2 ratio >300; Grade 2: PaO_2/FiO_2 ratio is 200–300; Grade 3: PaO_2/FiO_2 ratio <200. The use of ECMO for bilateral pulmonary edema on chest X-ray was classified grade 3.

Acute kidney injury (AKI)

AKI was defined using the Risk, Failure, Loss of kidney function, and End-stage kidney disease classification (27).

Echocardiographic evaluation

Pre- and post-lung transplant echocardiogram data were reviewed by cardiologists. In practice, postoperative TTE >90 days after lung transplantation was used for the analysis. Right and left heart function was evaluated using two-dimensional echocardiography. The evaluation parameters included RV function, RV diameter, tricuspid annular plane systolic excursion, intraventricular septum diameter, and other parameters as references for comprehensive diagnosis. RV function was also evaluated on a four-point scale using fractional area change as a two-dimensional surrogate for RV ejection fraction, severe right heart dysfunction was defined as <25%.

Results

Patient demographics

In total, 159 patients underwent lung transplantation during the study period. Of the 159 patients, 43 had COVID-19-associated ARDS as an indication for lung transplantation, including 2 patients who were excluded because of multi-organ transplantation. Therefore, a total of 41 patients were included in this study: 25 of the 41 patients underwent preoperative VV-ECMO; and, 16 patients did not have preoperative VV-ECMO (*Figure 1*). Data on the 25 lung transplant recipients, who had COVID-19-

Table 1 Characteristics of patients with COVID-19-associated ARDS divided by VV-ECMO bridge use

Variable	No VV-ECMO bridge (N=16)	VV-ECMO bridge (N=25)	P value
Recipient factors			
Age, years	54.5 [52.8–63]	53 [36–55]	0.04
Female	7 (43.8)	11 (44.0)	>0.99
BMI, kg/m^2	25.7±4.7	26.8±4.1	0.46
Smoking history	4 (25.0)	3 (12.0)	0.51
Hypertension	9 (56.3)	10 (40.0)	0.49
Diabetes	7 (43.8)	8 (32.0)	0.67
Bilateral	15 (93.8)	25 (100.0)	0.82
LAS	74.9 [57.8–83.1]	88.1 [87.3–92.4]	<0.001
Days on waiting list	13.5 [9–24.5]	6 [4–15]	0.10
Laboratory			
Hemoglobin, g/dL	10.5±1.6	7.7±0.9	<0.001
WBC, 1,000/mm^3	8.1±2.3	10.7±4.7	0.04
Platelets, 1,000/mm^3	295.3±137.1	171.6±68.9	<0.001
BUN, mg/dL	15.1±8.4	23.2±13.9	0.04
Creatinine, mg/dL	0.64±0.15	0.58±0.26	0.44
Albumin, g/dL	3.8±0.5	3.5±0.6	0.11
INR	1.1±0.1	1.2±0.1	0.001
Arterial blood gas			
pH	7.35±0.08	7.42±0.05	<0.001
$PaCO_2$	57.3±15.9	46.6±9.6	0.02
PaO_2	256.3±109.1	161.5±86.4	0.006
Donor			
Age, years	27.5 [22.3–35.5]	35 [25–41]	0.16
Female	6 (37.5)	8 (32.0)	0.98
Cause of death			
Anoxia	8 (50.0)	8 (32.0)	0.41
Head trauma	7 (43.8)	12 (48.0)	>0.99

Continuous data are shown as mean ± SD, median and interquartile range [Q1–Q3] or n (%). COVID-19, coronavirus disease 2019; ARDS, acute respiratory distress syndrome; VV-ECMO, veno-venous extracorporeal membrane oxygenation; BMI, body mass index; LAS, lung allocation score; WBC, white blood cell; BUN, blood urea nitrogen; INR, international normalized ratio; SD, standard deviation.

associated ARDS with VV-ECMO bridge, is summarized in Supplemental *Table 1*. Patients were supported with VV-ECMO for a median of 81 [interquartile range (IQR), 52–126] days. After achieving hemodynamic stability, all patients underwent aggressive preoperative rehabilitation, except for the first recipient, and did not require inotropic drugs or inhaled nitric oxide postoperatively (Table S1). Compared to patients without preoperative VV-ECMO, those with VV-ECMO bridge were younger and had lower hemoglobin and platelet counts. They also had a higher white blood cell count, blood urea nitrogen level, and international normalized ratio (*Table 1*). The median lung

Table 2 Intraoperative outcomes of lung transplant recipients with COVID 19-associated ARDS divided by VV-ECMO bridge use

Variable	No VV-ECMO bridge (N=16)	VV-ECMO bridge (N=25)	P value
Operative time (hours)	7.8 [7.3–8.1]	9.5 [8.3–10.3]	<0.001
Intra-op blood transfusion			
pRBC	2 [0.8–3]	10 [7–17]	<0.001
FFP	0 [0–0]	4 [2–8]	<0.001
Plt	0 [0–0]	3 [2–4]	<0.001
Ischemic time (hours)	5.6 [4.8–5.8]	6 [5.3–6.3]	0.04
VA ECMO use	15 (93.8)	24 (96.0)	>0.99
VA ECMO time (hours)	5.6 [4.8–5.8]	6 [5.3–6.3]	0.04

Continuous data are shown as median and interquartile range [Q1–Q3] or n (%). COVID-19, coronavirus disease 2019; ARDS, acute respiratory distress syndrome; VV-ECMO, veno-venous extracorporeal membrane oxygenation; pRBC, packed red blood cells; FFP, fresh frozen plasma; Plt, platelets; VA ECMO, veno-arterial extracorporeal membrane oxygenation.

allocation score (LAS) of patients with the VV-ECMO bridge was 88.1 (IQR, 87.3–92.4), higher than the 74.9 (IQR, 57.8–83.1) of patients without the VV-ECMO bridge (*Table 1*). In addition, during the study period, there were 15 deaths while on the waiting list, eight of which were COVID-19-associated ARDS (Table S2). Six of the eight cases had an ECMO bridge (Table S2).

Intra- and postoperative outcomes after lung transplantation

There was no significant difference in the rate of intraoperative veno-arterial (VA)-ECMO use between patients with and without a VV-ECMO bridge. However, patients with VV-ECMO bridge required a longer VA-ECMO time, operative time, ischemic time, and volume of blood transfusion (*Table 2*).

Postoperatively, patients with VV-ECMO bridge had a higher incidence of complications after lung transplantation (*Table 3*). In the VV-ECMO bridge group, PGD grade 3 occurred in 44% and AKI in 76% of the patients, which was significantly higher than that in cases without VV-ECMO. As a result, patients required a higher rate of postoperative VV-ECMO use, longer intensive care unit (ICU) stay, and longer hospital stay (*Table 3*). In the Kaplan-Meier analysis, the one-year survival rate for patients with VV-ECMO bridge was 78.3%, which was lower than the 100.0% rate for patients without the VV-ECMO bridge (P=0.06). However, the one-year mortality rate for 113 patients with other lung transplant indications during the same study period was 84.2%, which was nearly equivalent (P=0.95) (*Table 3* and *Figure 2*).

Echocardiogram results of pre- and post-lung transplantation for the patients with VV-ECMO bridge

Comparing preoperative and postoperative TTE results, the median mitral A-wave velocity decreased from 0.70 (IQR, 0.7–0.8) to 0.70 (IQR, 0.5–0.8) cm/s, the median right ventricular systolic pressure (RVSP) decreased from 45.7 to 29.0 mmHg (*Figure 3* and Table S3). There was no significant difference between the findings related to left heart structure and function, such as left ventricular internal dimensions at end-diastole and end-systole, left atrial volume index, and ejection fraction (*Figure 4* and Table S3).

Discussion

We present a single-center case series of consecutive patients who underwent lung transplantation with preoperative VV-ECMO for COVID-19-associated ARDS. Even though the ECMO team had been established for years, the management of COVID-19 patients presented many challenges due to their novelty. In addition, the management of COVID-19 and lung transplantation provided an opportunity to develop communication and clinical care among the multidisciplinary team, as management strategies for these patients require rapid adaptation (28). In this study, neither myocardial augmentation nor inhaled nitric oxide was used in any of the patients after lung transplantation, and echocardiographic findings showed improved postoperative RVSP after lung transplantation. All patients with COVID-19-associated ARDS, who were supported with VV-ECMO, developed severe RHF and were supported with VV-ECMO for

Table 3 Postoperative outcomes of lung transplant recipients with COVID-19-associated ARDS divided by VV-ECMO bridge use

Variable	No VV-ECMO bridge (N=16)	VV-ECMO bridge (N=25)	P value
PGD	8 (50.0)	18 (72.0)	0.24
PGD grade 3	0 (0)	11 (44.0)	0.006
AKI	4 (25.0)	19 (76.0)	0.004
Dialysis	1 (6.3)	10 (40.0)	0.04
Digital ischemia	0 (0)	1 (4.0)	>0.99
ICU stay (days)	13 [8.8–18.8]	20 [15–31]	0.03
Post-transplant ventilator (days)	3 [1.8–14.8]	9 [3–17]	0.39
Hospital stay (days)	19.5 [15.8–25.3]	35 [23–38]	0.02
Post-ECMO use	0 (0)	19 (76.0)	<0.001
Post-op ECMO days	0 [0–0]	4 [1–6]	<0.001
Survival	16 (100.0)	19 (76.0)	0.10
One-year survival	100.0%	78.3%	0.06
Follow-up period (days)	417 [389.5–506]	448 [314–664]	0.60

Continuous data are shown as median and interquartile range [Q1–Q3] or n (%). COVID-19, coronavirus disease 2019; ARDS, acute respiratory distress syndrome; VV-ECMO, veno-venous extracorporeal membrane oxygenation; PGD, primary graft dysfunction; AKI, acute kidney injury; ICU, intensive care unit.

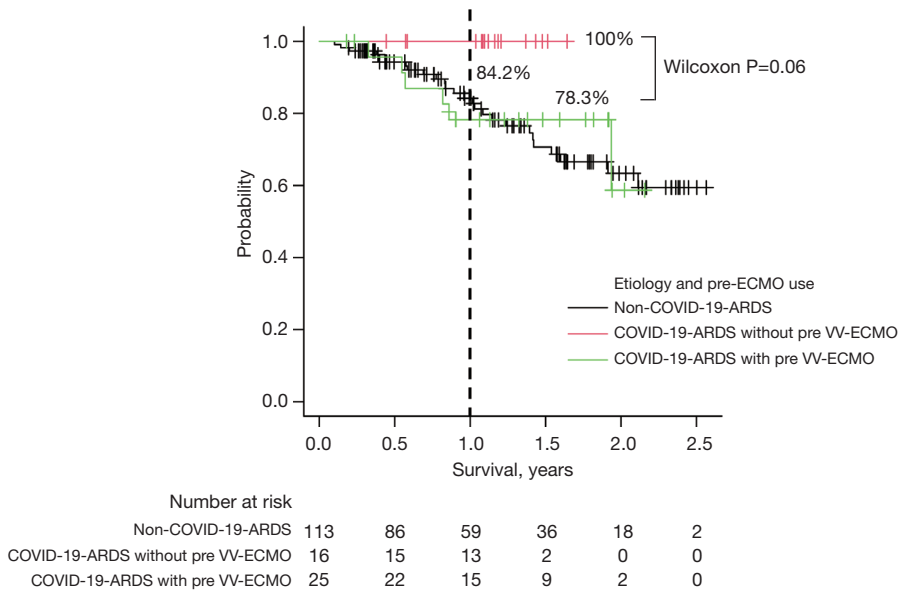

Figure 2 Kaplan-Meier analysis of overall survival after lung transplantation. Comparison of the survival rates among COVID-19-associated ARDS patients with VV-ECMO, COVID-19-associated ARDS without VV-ECMO bridge, and non-COVID-19-associated ARDS group. COVID-19, coronavirus disease 2019; ARDS, acute respiratory distress syndrome; VV-ECMO, veno-venous extracorporeal membrane oxygenation.

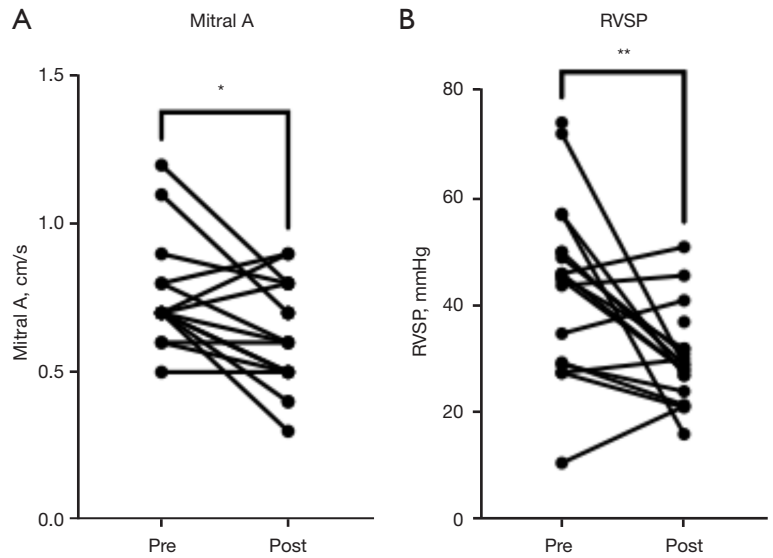

Figure 3 Wilcoxon signed-rank test for echocardiogram results of mitral A-wave velocity (A) and RVSP (B) before and after lung transplantation. *, P<0.05; **, P<0.01. RVSP, right ventricular systolic pressure.

81 days as a median. Even with relatively long-term VV-ECMO support before lung transplantation, no major ECMO-related complications, such as thrombosis, hemorrhagic stroke, gastrointestinal bleeding, cannula-related complications, or sepsis, occurred preoperatively. The absence of these complications suggests that long-term VV-ECMO support may be a feasible and safe bridge to lung transplantation in patients with COVID-19-associated ARDS complicated by severe RHF.

Postoperative survival curves showed that patients who received VV-ECMO support had a lower one-year survival rate than that of patients who did not receive support. However, the survival rates were similar to those of patients with indications for transplantation, other than COVID-19-associated ARDS. Patients on VV-ECMO support had a higher LAS and relatively severe disease, resulting in higher postoperative complication rates and longer postoperative ICU and hospital stays, which may have influenced this difference in survival rates. Among patients with COVID-19-associated ARDS, the use of VV-ECMO resulted in more severe disease before and after lung transplantation. One-year survival rates for lung transplantation for ARDS have been reported to be 71.6–82.1% (5,6,29,30), and for ECMO bridge lung transplantation including chronic disease, 70–79% (6,31-34). Compared to these results, the 1-year survival rate after transplantation with an ECMO bridge for COVID-19-related ARDS was almost equal at 78.3%. To reduce complications during VV-ECMO support, several unique protocols have been developed in our center: (I) no systemic anticoagulation during VV-ECMO support can reduce bleeding complications and blood transfusion rates without increasing the risk of thrombotic complications (21,22): (II) use of surveillance blood cultures and routine changes in CVCs to reduce infection risk (23); and (III) early initiation of physical therapy improves functional activity (35).

All of COVID-19-associated ARDS patients who used VV-ECMO preoperatively was converted from VV ECMO to VA ECMO (a VV-ECMO cannula was used for drainage in advance, and an outflow cannula was cannulated into the ascending aorta). After both lungs were implanted, the aortic cannula was removed and returned to or decannulated VV-ECMO. The decision to whether going back on VV ECMO or decannulate in an operating room was made depending on the RV function and transplanted lung function.

At our institution, we have preferentially used dual lumen cannulas that have an outflow into the pulmonary artery. The advantage of these cannulas is that they assist the right heart by offloading the RV (36). Recent studies have shown improved survival rates in COVID-19-associated ARDS with the use of the such cannulas (15,37-39). Hence, ECMO with the dual lumen cannulas may be helpful in supporting RV failure and reducing waitlist mortality, and multiorgan dysfunction such as AKI (40). Because of these advantages, this cannula could be increasingly used as a bridge to lung

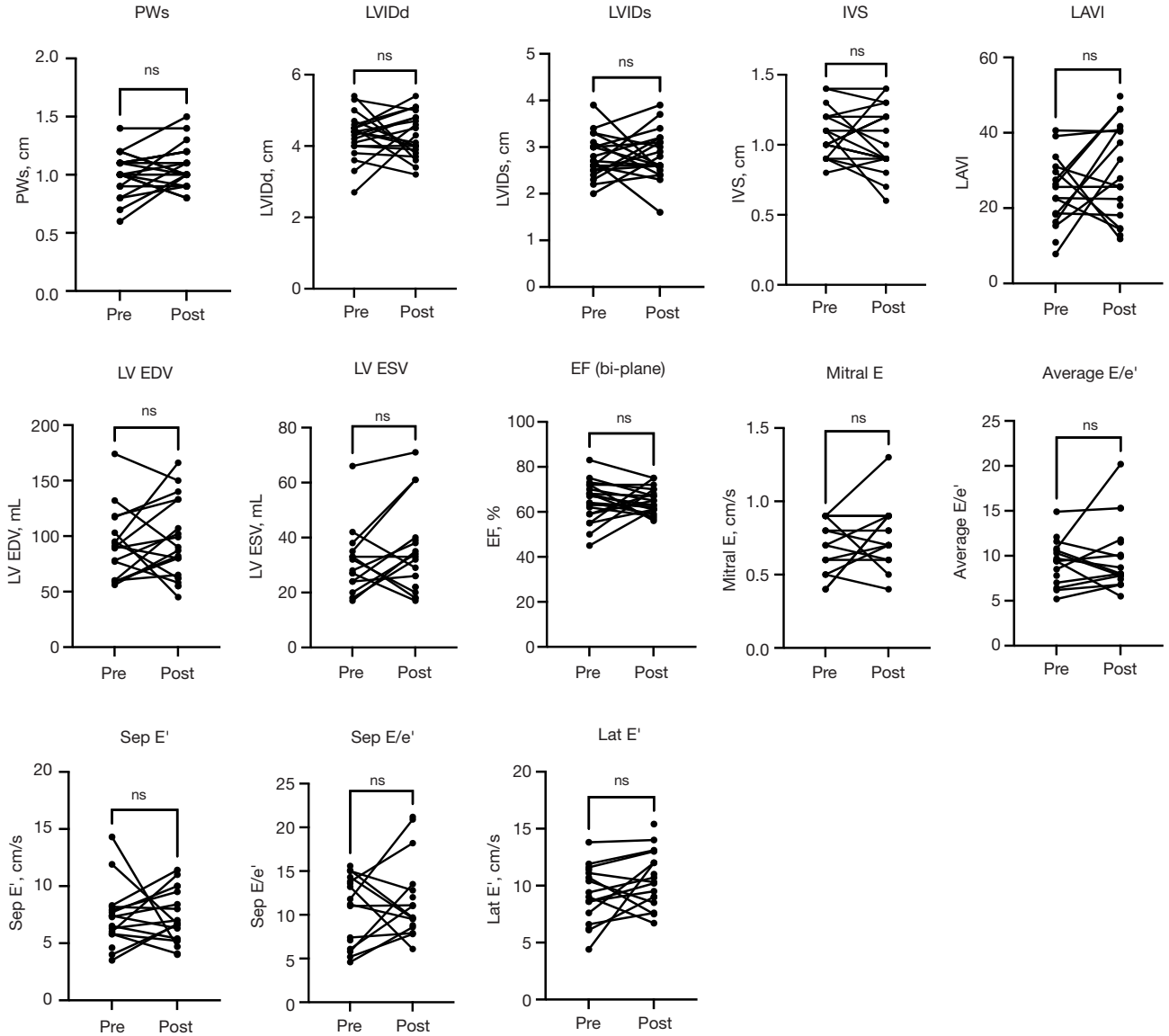

Figure 4 Wilcoxon signed-rank test for echocardiogram results before and after lung transplantation. PWs, posterior walls; LVIDd, left ventricular internal dimensions in end-diastole; LVIDs, left ventricular internal dimensions in end-systole; IVS, intraventricular septum; LAVI, left atrial volume index; LV EDV, left ventricular end-diastolic volume; LV ESV, left ventricular end-systolic volume; EF, ejection fraction; Sep, septum; Lat, lateral; ns, not significant.

transplantation, and this case series highlights its safety and feasibility.

Preoperative and postoperative echocardiography revealed recovery of RVSP after lung transplantation. Although comparisons of pulmonary vascular resistance and cardiac output were not possible due to a lack of data, this study suggests that lung transplantation alone could improve right heart function in patients with severe RHF. Whether heart-lung transplantation or lung transplantation alone is indicated for severe heart failure is a topic that has long been discussed in the field of pulmonary hypertension (41-43). Compared to patients with pulmonary hypertension, patients with COVID-19-associated ARDS have a relatively short course with mild structural remodeling; thus, morphological and functional recovery of the right heart system after surgery is expected to be fast. Therefore, lung transplantation alone, rather than heart-lung transplantation, has advantages, and our

echocardiographic data supports these hypotheses.

Limitations

This study has several limitations. First, this study was single-center and relatively small in nature. Furthermore, since these results are based on the experiences of a small cohort in a single large institution, differences in referral patterns, ECMO management, and eligibility criteria cannot be generalized and must be considered. New variants of varying pathogenicity, the efficacy and impact of vaccination and novel therapies, and changes in the socioeconomic impact of the disease are well encompassed in the timeframe of this study, but are not controlled for in this analysis.

Conclusions

VV-ECMO is a feasible and effective safe bridge to lung transplantation in patients with COVID-19-associated ARDS and severe RHF.

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Footnote

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-132/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-132/coif). A.B. was supported by the National Institutes of Health (HL145478, HL147290, and HL147575). The other authors have no conflicts of interest to declare.

Ethical 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 study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Northwestern University (Nos. STU00207250 and STU00213616). The need for patient consent for data collection was waived by the institutional review board because this was a retrospective study.

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