Review

SAGE Open Medicine

SAGE Open Medicine
Volume 12: 1–7

DOI: 10.1177/20503121241275410
journals.sagepub.com/home/smo
Sage

Venopulmonary extracorporeal membrane oxygenation for right ventricular support as a bridge to lung transplantation: A narrative review

Phan Quang Thuan[1], Nguyen Hoai Nam[2] and Nguyen Hoang Dinh[1,2]

Abstract

This review evaluates the effectiveness of veno-pulmonary support with an oxygenator using extracorporeal membrane oxygenation as a bridge to lung transplantation strategy in patients undergoing veno-venous extracorporeal membrane oxygenation while awaiting lung transplantation. Examining indications, contraindications, and clinical outcomes, the study highlights potential benefits, drawing insights from successful cases in South Korea and the United States. Despite limited sample sizes, veno-pulmonary support with an oxygenator using extracorporeal membrane oxygenation emerges as a promising approach for further investigation in lung transplantation support. The review emphasizes its role in improving hemodynamic status, preventing complications during extended waiting periods, and presenting a cost-effective alternative to traditional methods, especially in developing countries. While in-hospital mortality rates range from 0% to 10%, comparable to other approaches, cautious optimism surrounds veno-pulmonary support with an oxygenator using extracorporeal membrane oxygenation, urging expanded research to solidify its standing in enhancing patient outcomes, reducing costs, and promoting transplant success.

Keywords

Veno-pulmonary support with an oxygenator using extracorporeal membrane oxygenation (V-P ECMO), Bridge to lung transplantation (BTT), Lung transplantation (LTx)

Date received: 18 March 2024; accepted: 30 July 2024

Introduction

Lung transplantation (LTx) has become the established standard of care for individuals suffering from nonmalignant end-stage lung disease (ESLD).[1–4] Despite the global expansion of lung transplant centers, a significant number of patients worldwide find themselves on waiting lists due to the scarcity of donor organs.[5–7] Consequently, many patients experience prolonged wait times, leading to increased mortality rates while awaiting transplantation.[6,8,9] Addressing this issue, patients in need of LTx often require respiratory support during the waiting period. Veno-venous extracorporeal membrane oxygenation (V-V ECMO), which supports respiratory function, emerges as a potential solution to serve as a bridge to lung transplantation (BTT).[2,6,10]

However, a recognized complication of V-V ECMO is right heart decompensation (RHD), causing hemodynamic instability.[11,12] Urgent support becomes imperative in such situations, necessitating immediate interventions that encompass both cardiac and respiratory support.[13] These interventions may involve additional arterial cannulation or transitioning to veno-arterial (V-A ECMO) or veno-arterialvenous ECMO (V-AV ECMO).[2,10,11,13–16] Nevertheless, the shift to or augmentation of V-A ECMO introduces potential complications, such as an elevated risk of device-related issues, including bleeding,

[1]Department of Cardiovascular Surgery, University Medical Center HCMC, University of Medicine and Pharmacy at Ho Chi Minh City, Ho Chi Minh City, Vietnam
[2]Department of Cardiovascular and Thoracic Surgery, Faculty of Medicine, University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam

Corresponding author:
Nguyen Hoang Dinh, Department of Cardiovascular Surgery, University Medical Center HCMC, University of Medicine and Pharmacy at Ho Chi Minh City, Ho Chi Minh City, Vietnam.
Email: dinh.nh@umc.edu.vn

Table 1. Indications and contraindications for V-P ECMO in V-V ECMO patients as a BTT.

Indications
Right heart failure in the setting of ESLDs with V-V ECMO support
RHD in V-V ECMO
Hemodynamic instability despite maximal correction
Multiorgan dysfunction due to insufficient oxygen delivery with V-V ECMO
Respiratory failure not maintaining adequate oxygenation despite 100% Fraction of Inspired Oxygen (FiO2) supplementation with V-V ECMO
Absolute contraindications
Irreversible multiorgan damage (other than lungs)
Patients with poorly controlled multiorgan dysfunction are not suitable candidates for a multiorgan transplant
The presence of malignancy that indicates a significant likelihood of recurrence within the initial 2 years following LTx
Uncorrectable bleeding disorder
Unmanaged infection with highly virulent and/or drug-resistant microbes
Unmanaged active mycobacterium tuberculosis infection
Psychiatric or psychological issues likely rendering the patient unable to comply with a complicated medical regimen
Relative contraindications
Individuals aged over 65 years
Significant malnutrition
Significant osteoporosis
Colonization with resistant or highly virulent pathogens
High predictive prolonged necessity of mechanical ventilation
Previous cardiothoracic surgery

thromboembolism, and limb ischemia, potentially impeding early rehabilitation efforts.[17–19] Even though V-AV ECMO may provide efficient oxygenation and hemodynamic support while avoiding differential hypoxia, regulating the relative flow in the two outflow limbs (arterial and oxygenated venous) can pose challenges and is frequently unattainable in the advanced stages of lung disease.[16,20]

The utilization of veno-pulmonary (V-P), formerly known informally as the Oxygenator Right Ventricular Assist Device (Oxy-RVAD), has been proposed as an effective method to address RHD during V-V ECMO.[11,21] However, V-P devices are costly, making them potentially unsuitable for some patients.[11,22] To address this issue, researchers have introduced a novel approach: V-P support with an oxygenator using extracorporeal membrane oxygenation (V-P ECMO).[11,17,23,24] This method is particularly relevant for patients experiencing respiratory failure combined with RHD during V-V ECMO treatment as a BTT.

This review aims to evaluate the viability of the new approach in supporting RHD among patients undergoing V-V ECMO as a BTT. With limited current data available, the objective is to synthesize the authors' experiences, offering insights into the practical application of this method and providing a clinical perspective on addressing the issue.

Indications

Patients indicated for V-V ECMO while awaiting a lung transplant are those enlisted on the waiting list without any contraindications to LTx at the time of V-V ECMO prescription.[10,25,26] However, the use of V-V ECMO itself can induce RHD or progressive right ventricular failure (RVF) in the context of ESLD not directly related to V-V ECMO.[13,27–29] Additionally, patients may experience RVF due to factors beyond ESLD, requiring a distinct treatment approach for those awaiting LTx on V-V ECMO. It is important to note that this aspect is not covered in this review, and the focus specifically shifts toward addressing the root cause of RVF. Furthermore, the extended progression of ESLD leads to the development of secondary pulmonary hypertension (PH) alongside right heart failure, culminating in hypoxic respiratory failure despite V-V ECMO.[27,30] This underscores the intricate challenges associated with managing patients in this complex clinical scenario.

Table 1 outlines the indications for V-P ECMO.[16,17,23,31] These indications primarily pertain to two distinct categories:

- Progressive RVF stemming from ESLD or RHD induced by V-V ECMO.
- Progressive respiratory failure persisting despite V-V ECMO, attributed to secondary PH, RVF or a combination of both mechanisms.

While the clinical manifestations may vary, prompt identification of respiratory and circulatory failure is crucial for swiftly administering support. This immediate intervention aims to safeguard organ function and uphold the eligibility of patients on the waiting list.[23]

Contraindications

When V-V ECMO is indicated for patients awaiting LTx, contraindications to LTx are not present at that initial decision point. However, when considering the addition of V-P ECMO, reevaluation becomes necessary to determine the patient's current candidacy for LTx. It is crucial to re-evaluate and confirm that there are no contraindications before opting for V-P ECMO. If the patient is found to have contraindications for placement on the lung transplant list, consideration for treatment with V-P ECMO should be further excluded. It is essential to recognize that V-P ECMO primarily serves as a BTT. If the patient no longer meets the criteria or indications for organ transplant, they will be taken off the waiting list.

The contraindications outlined in Table 1 for V-P ECMO necessitate a thorough reassessment during the appointment for V-P ECMO to determine whether the patient presents contraindications to LTx.[3,31,32] In the presence of contraindications, careful consideration is essential to decide whether to proceed based on the individual's specific medical condition. These contraindications may be absolute or relative in nature.

Furthermore, patients with a history of prior cardiothoracic surgery require specific attention in the evaluation process.[33] Accessing the main pulmonary artery (MPA) through sternotomy or thoracotomy may pose challenges, although percutaneous and mini techniques are available.[19,34] While the latter methods offer alternatives, minimally invasive surgery may provide a more favorable resolution to this challenge, rendering prior cardiothoracic surgery a relative contraindication.

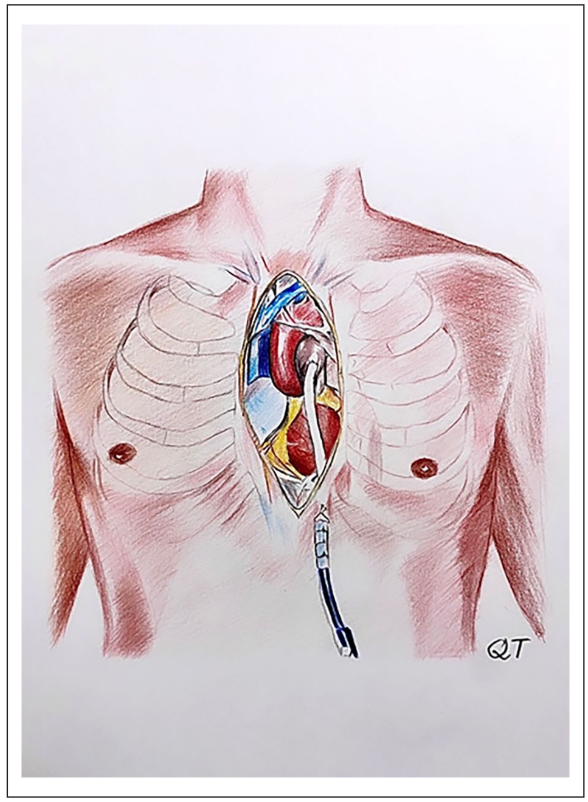

Figure 1. Full-sternotomy to insert a graft tube directly into the MPA.

V-P ECMO technique

Numerous methods exist for implementing VP support, including the use of a RVAD equipped with an oxygenator; however, this approach incurs significant costs.[21,35,36] To address this, the authors opted for an alternative by employing ECMO with an oxygenator, aiming to economize by repurposing the V-V ECMO system through a simple switch of cannula positions.[16,17] This involves redirecting venous blood from the right atrium through one cannula to the ECMO oxygenator and returning oxygenated blood to the MPA through another cannula.[16,17,27]

According to current medical literature, there are three established methods for cannula insertion into the MPA. The first method involves performing a full or mini sternotomy to insert a graft tube or to place the cannula directly into the MPA (Figure 1).[11,37–39] The second method entails opening the third or fourth intercostal space on the anterior thoracotomy as a graft tube or directly placing the cannula into the MPA (Figure 2).[16,17] The third method involves inserting a percutaneous cannula into the MPA.[40] Notably, in cases where the patient has undergone prior cardiothoracic surgery, the third method is particularly suitable.[41,42]

Cannula insertion into the right atrium can be performed percutaneously through the femoral vein or jugular vein, or directly into the right atrium via a full sternotomy or thoracotomy.[11,17,37,41,43,44] Percutaneous cannula placement is typically preferred due to its simplicity and minimal bleeding. However, when percutaneous access is not feasible—such as in cases of infection at the puncture site or absence of the superior and inferior vena cava—the full sternotomy or thoracotomy method is chosen.

This system ensures the maintenance of anterograde blood flow, prevents right ventricular distension, preserves transpulmonary blood flow, and mitigates complications associated with peripheral arterial cannulation, such as limb ischemia and Harlequin syndrome. This approach harmonizes well with patient requirements, minimizing complications when applying V-A ECMO or V-AV ECMO.

Clinical assessment and outcome

Following the transition from V-V ECMO to V-P ECMO or during support with V-P ECMO, there was notable improvement in the hemodynamic status associated with right heart failure. Key parameters indicative of right heart function, such as the peak tricuspid regurgitation velocity, demonstrated a significant decrease. Concurrently, there were significant increases observed in mean arterial blood pressure, coupled with noteworthy decreases in heart rates, levels of lactic acid, and the requirement for norepinephrine. Additionally, improvements were noted in other organ functions.[16,17,23,27] However, it is essential to acknowledge that some patients may experience pulmonary hemorrhage and edema attributable to elevated pulmonary arterial pressure,

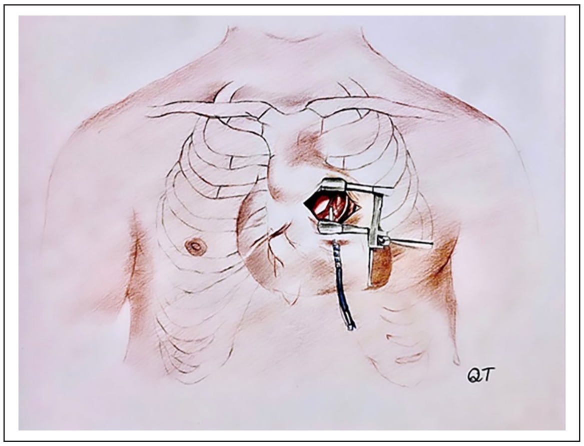

Figure 2. Opening the third intercostal space via left anterior thoracotomy to insert a graft tube into the MPA.

particularly in cases of severe PH. To mitigate these issues, it is advisable to regulate the flow effectively. This strategic control is instrumental in maintaining hemodynamic stability and mitigating complications associated with pulmonary hemorrhage and edema.[23,45,46]

In 2020, Sung Kwang Lee et al. in South Korea reported 14 cases of V-P ECMO performed on BTT patients undergoing V-V ECMO, with MPA access via left anterior thoracotomy. The study revealed that 10 patients underwent LTx with an average waiting time of 8 days from the initiation of V-P ECMO. Unfortunately, the remaining four patients succumbed to multiorgan failure during the ECMO process, with an average waiting time in this subgroup being 22.5 days. Notably, the LTx rate exceeded 70%, and the in-hospital mortality was only 10%. The 1-year survival rate stood at 8 out of 10 patients, reflecting an 80% success rate.[16] In comparison to the use of V-A ECMO or V-AV ECMO for BTT cases, patients receiving V-P ECMO demonstrated lower LTx rates and mortality rates. However, it is crucial to acknowledge that research with a limited sample size warrants expansion to ensure a more comprehensive and objective evaluation of the outcomes.[39,47]

In 2021, Jae Guk Lee et al. from South Korea conducted a review encompassing eight cases of patients who underwent V-P ECMO with MPA access through left anterior thoracotomy. Among these cases, seven patients, constituting 87.5%, successfully received LTx with an average waiting time of 20 days. The in-hospital mortality rate after transplant was reported as 0%, highlighting a favorable outcome. Notably, only one patient, accounting for 14.3%, succumbed to mortality 4 months postsurgery. These findings closely align with the results reported by author Sung Kwang Lee et al.[48]

In the United States, Nandavaram et al. in 2023 presented a study involving three cases of percutaneous V-P ECMO with an average waiting time of 60 days. All patients, totaling 100%, successfully underwent LTx, and the in-hospital mortality rate was reported as 0%. While the long-term outcomes

Table 2. V-P ECMO for bridging to LTx studies.

Author	Data source	Number of patients	Patient's LTx	MPA cannulation approach	Median ECMO bridge duration (days)	ECMO complication	In hospital mortality in patient's LTx (%)	Rehabilitation on ECMO (%)	References
Oh et al. (2020)	South Korea	1	1 (100%)	Left anterior thoracotomy	10	No	0	100	17
Lee and Kim (2020)	South Korea	14	10 (71.4%)	Left anterior thoracotomy	8	No	10	100	16
Sim et al. (2020)	South Korea	1	1 (100%)	Full Sternotomy	185	No	0	100	38
Lee et al. (2021)	South Korea	8	7 (87.5%)	Left anterior thoracotomy	20	No	0	87	48
Nandavaram et al. (2023)	United States	3	3 (100%)	Percutaneous cannulation	60	No	0	100	27

ECMO: extracorporeal membrane oxygenation; LTx: Lung transplantation; MPA: main pulmonary artery.

of the patients were not disclosed, the study underscores the viability of V-P ECMO as a safe and effective method for patients to await a donor organ, given the average waiting time of 2 months.[27] Additionally, the findings align with those of Jae Kyeom Sim et al.[38] in 2020, who reported a case of V-P ECMO with a waiting time of up to 185 days, further emphasizing the feasibility of this approach.

According to the authors' findings in Table 2, no significant complications associated with V-P ECMO were documented during the extended waiting period for LTx, even when support lasted up to 185 days. This supports the initial hypothesis, suggesting that V-A ECMO, used for right heart failure support, would likely lead to complications. Existing studies on V-A ECMO in patients awaiting lung transplants indicate complication rates between 4% and 12%.[49,50] Despite the limited sample size in studies of V-P ECMO, these outcomes align with our clinical rationale.

Rehabilitation plays a crucial role in readying patients for LTx, with significant advantages noted when utilizing the V-P ECMO system, as evidenced in Table 2. Despite the potential for the ECMO system to be cumbersome, it does not impede rehabilitation efforts for pain.[23] This not only enhances the pre-transplantation condition of patients but also mitigates complications related to infections and pressure ulcers arising from prolonged bed rest. Furthermore, it serves as empirical evidence that this method facilitates a more manageable physical therapy process compared to V-A ECMO, which is inherently more challenging for rehabilitation, and other RVADs, which tend to be more costly.

The V-P ECMO support duration can be sufficiently extended to accommodate the waiting period for a donor organ, with a lung transplant waiting success rate exceeding 70% and the longest waiting time reaching up to 185 days (see Table 2). In comparison to waiting for LTx with V-A ECMO or RVADs, the success rate is not inferior. This underscores the pivotal role of V-P ECMO in serving as a supportive bridge for LTx when RVF becomes evident, all the while maintaining a cost advantage over the use of a RVADs.[47,50] The in-hospital mortality rate for patients utilizing V-P ECMO in the context of LTx spans from 0% to 10%. However, when contrasted with patients employing other V-A ECMO or RVADs in a similar context, V-P ECMO does not exhibit superior outcomes.[50] Nevertheless, given the limited number of patients in the referenced studies, we hesitate to draw definitive conclusions. However, these findings serve as a foundational basis for future expansion and exploration.

Conclusion

LTx candidates undergoing prolonged V-V ECMO as a BTT may develop RVF, potentially resulting in hemodynamic instability. Implementing an effective ECMO strategy is crucial to maintain preoperative rehabilitation in these patients. This review suggests that V-P ECMO support could provide a viable BTT option, enabling rehabilitation for patients who develop RVF and hemodynamic instability during V-V ECMO. Furthermore, this approach is particularly beneficial in regions where the high costs associated with RVADs limit their accessibility.

Acknowledgements

None.

Author contributions

Writing: PQT. Critical review and revision: PQT and NHD. Final approval of the article: All authors. Accountability for all aspects of the work: All authors.

Availability of data and materials

All of the material is available and owned by the authors and/or no permissions are required.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Phan Quang Thuan https://orcid.org/0000-0003-4523-7442

References

1. Thomas J, Chen Q, Malas J, et al. Impact of minimally invasive lung transplantation on early outcomes and analgesia use: a matched cohort study. *J Heart Lung Transplant* 2024; 43(8): 1358–1366.
2. Mattar A, Chatterjee S and Loor G. Bridging to lung transplantation. *Crit Care Clin* 2019; 35(1): 11–25.
3. Leard LE, Holm AM, Valapour M, et al. Consensus document for the selection of lung transplant candidates: an update from the International Society for Heart and Lung Transplantation. *J Heart Lung Transplant* 2021; 40(11): 1349–1379.
4. Bos S, Vos R, Van Raemdonck DE, et al. Survival in adult lung transplantation: where are we in 2020? *Curr Opin Organ Transplant* 2020; 25(3): 268–273.
5. Shah P and Neujahr DC. Lung transplantation: candidate selection and timing of transplant. *Curr Opin Organ Transplant* 2021; 26(3): 302–308.
6. Loor G, Simpson L and Parulekar A. Bridging to lung transplantation with extracorporeal circulatory support: when or when not? *J Thorac Dis* 2017; 9(9): 3352–3361.
7. Brahmbhatt JM, Hee Wai T, Goss CH, et al. The lung allocation score and other available models lack predictive accuracy for post-lung transplant survival. *J Heart Lung Transplant* 2022; 41(8): 1063–1074.
8. The Lancet Respiratory Medicine. The long wait for lungs. *Lancet Respir Med* 2018; 6(10): 727.

9. Deitz RL, Emerel L, Chan EG, et al. Waitlist mortality and extracorporeal membrane oxygenation bridge to lung transplant. *Ann Thorac Surg* 2023; 116(1): 156–162.
10. Faccioli E and Inci I. Extracorporeal life support as a bridge to lung transplantation: a narrative review. *J Thorac Dis* 2023; 15(9): 5221–5231.
11. Lorusso R, Whitman G, Milojevic M, et al. 2020 EACTS/ELSO/STS/AATS expert consensus on post-cardiotomy extracorporeal life support in adult patients. *J Thoracic Cardiovasc Surg* 2021; 161(4): 1287–1331.
12. Khorsandi M, Keenan J, Adcox M, et al. Diagnosis and treatment of right ventricular dysfunction in patients with COVID-19 on veno-venous extra-corporeal membrane oxygenation. *J Cardiothorac Surg* 2022; 17(1): 282.
13. Brown TN and Brogan TV. Right ventricular dysfunction in patients with acute respiratory distress syndrome receiving venovenous extracorporeal membrane oxygenation. *Front Cardiovasc Med* 2023; 10: 101027300.
14. Ius F, Sommer W, Tudorache I, et al. Veno-veno-arterial extracorporeal membrane oxygenation for respiratory failure with severe haemodynamic impairment: technique and early outcomes. *Interact Cardiovasc Thorac Surg* 2015; 20(6): 761–767.
15. Bunge JJH, Caliskan K, Gommers D, et al. Right ventricular dysfunction during acute respiratory distress syndrome and veno-venous extracorporeal membrane oxygenation. *J Thorac Dis* 2018; 10(Suppl 5): S674–S682.
16. Lee S and Kim D. Oxy right ventricular assist device using extracoporeal membrane oxygenation as a bridge to lung transplant for right ventricular failure. *J Heart Lung Transplant* 2020; 39(4, Supplement): S384.
17. Oh DK, Shim TS, Jo KW, et al. Right ventricular assist device with an oxygenator using extracorporeal membrane oxygenation as a bridge to lung transplantation in a patient with severe respiratory failure and right heart decompensation. *Acute Crit Care* 2020; 35(2): 117–121.
18. Jayaraman AL, Cormican D, Shah P, et al. Cannulation strategies in adult veno-arterial and veno-venous extracorporeal membrane oxygenation: techniques, limitations, and special considerations. *Ann Card Anaesth* 2017; 20(Supplement): S11–S18.
19. Lepper PM, Hörsch SI, Seiler F, et al. Percutaneous mechanical circulation support combined with extracorporeal membrane oxygenation (oxyRVAD) in secondary right heart failure. *ASAIO J* 2018; 64(4): e64–e67.
20. Makdisi Wang IW. Extra Corporeal Membrane Oxygenation (ECMO) review of a lifesaving technology. *J Thorac Dis* 2015; 7(7): E166–E176.
21. Kapur NK, Esposito ML, Bader Y, et al. Mechanical circulatory support devices for acute right ventricular failure. *Circulation* 2017; 136(3): 314–326.
22. Nunes AJ, MacArthur RGG, Kim D, et al. A systematic review of the cost-effectiveness of long-term mechanical circulatory support. *Value Health* 2016; 19(4): 494–504.
23. Lee SK, Kim DH, Cho WH, et al. Oxy-right ventricular assist device for bridging of right heart failure to lung transplantation. *Transplantation* 2021; 105(7): 1610–1614.
24. Brewer JM, Broman LM, Swol J, et al. Standardized nomenclature for peripheral percutaneous cannulation of the pulmonary artery in extracorporeal membrane oxygenation: current uptake and recommendations for improvement. *Perfusion* . Epub ahead of print 6 November 2023. DOI: 10.1177/02676591231210457
25. Biscotti M, Sonett J and Bacchetta M. ECMO as bridge to lung transplant. *Thorac Surg Clin* 2015; 25(1): 17–25.
26. Todd EM, Biswas Roy S, Hashimi AS, et al. Extracorporeal membrane oxygenation as a bridge to lung transplantation: a single-center experience in the present era. *J Thorac Cardiovasc Surg* 2017; 154(5): 1798–1809.
27. Nandavaram S, Keshavamurthy S and Gurley J. (1181) Successful use of percutaneous right ventricular assist device with oxygentaor (oxyrvad) as a bridge to lung transplantation. *J Heart Lung Transplant* 2023; 42(4): S506.
28. Kolb TM and Hassoun PM. Right ventricular dysfunction in chronic lung disease. *Cardiol Clin* 2012; 30(2): 243–256.
29. Leopold JA, Kawut SM, Aldred MA, et al. Diagnosis and treatment of right heart failure in pulmonary vascular diseases: a national heart, lung, and blood institute workshop. *Circ Heart Fail* 2021; 14(6): e007975.
30. Olsson KM, Corte TJ, Kamp JC, et al. Pulmonary hypertension associated with lung disease: new insights into pathomechanisms, diagnosis, and management. *Lancet Respir Med* 2023; 11(9): 820–835.
31. Weill D. Lung transplantation: indications and contraindications. *J Thorac Dis* 2018; 10(7): 4574–4587.
32. Son J and Shin C. Indications for lung transplantation and patient selection. *J Chest Surg* 2022; 55(4): 255–264.
33. Roselli EE. Reoperative cardiac surgery: challenges and outcomes. *Tex Heart Inst J* 2011; 38(6): 669–671.
34. Said SM. Minimally invasive pulmonary valve replacement via left anterior minithoracotomy. *JTCVS Tech* 2021; 6: 127–129.
35. George TJ, Sheasby J, Kabra N, et al. Temporary right ventricular assist device support for acute right heart failure: a single-center experience. *J Surg Res* 2023; 282: 15–21.
36. Miller LW, Guglin M and Rogers J. Cost of ventricular assist devices. *Circulation* 2013; 127(6): 743–748.
37. Pooboni SK and Gulla KM. Vascular access in ECMO. *Indian J Thorac Cardiovasc Surg* 2021; 37(Suppl 2): 221–231.
38. Sim JK, Jeon K, Suh GY, et al. Successful lung transplantation after 213 days of extracorporeal life support: role of oxygenator-right ventricular assist device. *ASAIO J* 2021; 67(7): e127–e130.
39. Keshavamurthy S, Bazan V, Tribble TA, et al. Ambulatory extracorporeal membrane oxygenation (ECMO) as a bridge to lung transplantation. *Indian J Thoracic Cardiovasc Surg* 2021; 37(3): 366–379.
40. Usman AA, Spelde AE, Cevasco M, et al. Technical considerations for percutaneous pulmonary artery cannulation for mechanical circulatory support. *JTCVS Tech* 2023; 18: 65–73.
41. Joubert K, Harano T, Pilewski J, et al. Oxy-RVAD support for lung transplant in the absence of inferior vena cava. *J Card Surg* 2020; 35(12): 3603–3605.
42. Harano T, Chan EG, Furukawa M, et al. Oxygenated right ventricular assist device with a percutaneous dual-lumen cannula as a bridge to lung transplantation. *J Thoracic Dis* 2022; 14(4): 832.
43. Budd AN, Kozarek K, Kurihara C, et al. Use of protekduo as veno-arterial and veno-venous extracorporeal membrane

oxygenation during bilateral lung transplantation. *J Cardiothorac Vasc Anesth* 2019; 33(8): 2250–2254.

44. Kirklin JK, Pagani FD, Goldstein DJ, et al. American Association for Thoracic Surgery/International Society for Heart and Lung Transplantation guidelines on selected topics in mechanical circulatory support. *J Thorac Cardiovasc Surg* 2020; 159(3): 865–896.
45. Toporoff B, Marini CP, Grubbs PE Jr., et al. Pulmonary complications of a roller pump right ventricular assist device. *J Surg Res* 1988; 45(1): 21–27.
46. Welp H, Sindermann JR, Deschka H, et al. Pulmonary bleeding during right ventricular support after left ventricular assist device implantation. *J Cardiothorac Vasc Anesth* 2016; 30(3): 627–631.
47. Loor G, Chatterjee S and Shafii A. Extracorporeal membrane oxygenation support before lung transplant: a bridge over troubled water. *JTCVS Open* 2021; 8: 147–154.
48. Lee JG, Pak C, Oh DK, et al. Right ventricular assist device with extracorporeal membrane oxygenation for bridging right ventricular heart failure to lung transplantation: a single-center case series and literature review. *J Cardiothorac Vasc Anesth* 2022; 36(6): 1686–1693.
49. Xia Y, Ragalie W, Yang EH, et al. Venoarterial versus venovenous extracorporeal membrane oxygenation as bridge to lung transplantation. *Ann Thorac Surg* 2022; 114(6): 2080–2086.
50. Faccioli E, Terzi S, Pangoni A, et al. Extracorporeal membrane oxygenation in lung transplantation: indications, techniques and results. *World J Transplant* 2021; 11(7): 290–302.