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Post-pericardiectomy ECMO for constrictive pericarditis: a case series and literature review

Bin Jia[1†], Shujie Yan[2†], Yong Luo[1], Jian Cheng[1], Jie Cheng[1], Junjie Fei[1], Yushuang Gao[1], Xiao Liao[1], Luyu Bian[2], Jian Wang[2], Yuan Teng[2], Gang Liu[2], Lanying Gao[1*] and Bingyang Ji[2*]

Abstract

Background Pericardiectomy is the curative treatment for constrictive pericarditis, yet postoperative low cardiac output syndrome (LCOS) may occur. The application of venoarterial extracorporeal membrane oxygenation (VA-ECMO) in post-pericardiectomy refractory LCOS has limited case reports, and its effectiveness and safety remain unclear. This study aims to provide evidence for the effectiveness of ECMO in treating post-pericardiectomy refractory LCOS.

Methods Nine cases of post-pericardiectomy ECMO from two high-volume pericardiectomy centers in China were retrospectively reviewed. Meanwhile, a literature search was performed in PubMed and Embase on December 4, 2024. After screening, 5 articles were finally included for data extraction and comprehensive analysis.

Results Case Series: There were 4 cases of tuberculous etiology, 1 with a history of cardiac surgery, and 4 idiopathic cases. All patients were in New York Heart Association class III - IV at baseline. All the patients undertwent pericardiectomy via median sternotomy, and 5 patients underwent concomitant valve procedures. One patient failed to wean from the cardiopulmonary bypass (CPB) and was transferred to femoral VA-ECMO. Eight patients received femoral VA-ECMO support 4–96 h after surgery due to refractory LCOS. All the patients survived to discharge with good neurological outcomes after 120–192 h of ECMO support. Two patient were lost to follow-up, and the rest 7 patients survived to follow-up with a mean follow-up of 56 months. Literature Review: 4 case reports and 1 retrospective study were identified. In the retrospective study of 69 patients, 8 received ECMO during or after pericardiectomy with a hospital mortality rate of 63%. The four Patients of the 4 case reports were all survival at hospital discharge.

Conclusions VA-ECMO might be effective for refractory LCOS after pericardiectomy in patients with constrictive pericarditis, and could improve survival rates.

Keywords Extracorporeal membrane oxygenation (ECMO), Pericardiectomy, Constrictive pericarditis

†Bin Jia, and Shujie Yan contributed equally.

*Correspondence:
Lanying Gao
953043721@qq.com
Bingyang Ji
jibingyang@fuwai.com
[1]Department of Cardiovascular Surgery, The third People's Hospital of Chengdu, Chengdu, Sichuan, Chaina, China
[2]Department of Cardiopulmonary Bypass, Fuwai Hospital, National Center for Cardiovascular Disease, Beijing, China

Background

Constrictive pericarditis is a chronic inflammatory process involving pericardial inflammation, fibrosis, and calcification. The thickened and non-compliant pericardium restricts diastolic filling of both ventricles, ultimately leading to heart failure. Moreover, the inflammatory and fibrotic processes can infiltrate the ventricular wall, resulting in myocardial atrophy and fibrosis, further impairing myocardial function, with a greater impact on the right ventricle (RV) than the left ventricle (LV) [1].The prevalence of constrictive pericarditis remains unclear. In developing countries, tuberculosis is the most common cause, while in developed countries, idiopathic constrictive pericarditis prevails. Other causes include infections by other pathogens, previous surgeries, prior mediastinal radiotherapy, and connective tissue diseases. The clinical manifestations of constrictive pericarditis are related to left and right heart failure and elevated filling pressures. Pericardiectomy is the curative treatment for constrictive pericarditis and should be performed as completely as possible when technically feasible.

Postoperative low cardiac output syndrome (LCOS) is not uncommon in these patients, due to preoperative myocardial damage and the rapid increase in ventricular preload after pericardial decompression [2]. Extracorporeal membrane oxygenation (ECMO) may be a potential treatment for refractory post-pericardiectomy low cardiac output syndrome. Although ECMO is commonly used after cardiac surgeries to facilitate cardiac recovery from myocardial stunning or injury, its effectiveness after pericardiectomy has not been fully confirmed. Given that the primary mechanisms of post-pericardiectomy LCOS differ from those of LCOS following other types of cardiac surgery, where the former is primarily due to the ventricles' poor compliance and inability to adapt to the sudden increase in volume load after removal of the constrictive pericardium, while the latter is mainly caused by ischemia-reperfusion injury and intraoperative myocardial damage, it is valuable to conduct a dedicated study on the effectiveness of ECMO for post-pericardiectomy LCOS. However, limited case reports have described the use of ECMO after pericardiectomy as pericardiectomy is a highly specialized and relatively uncomon procedure due to the low prevalence of constrictive pericarditis and surgical complexity of the procedure.

To address this issue, in this study, we report 9 cases of ECMO use after pericardiectomy from two high-volume pericardiectomy centers in China and review the existing literature reporting similar cases. This study aims to provide evidence for the effectiveness of ECMO in treating LCOS after pericardiectomy.

Methods

Case series

This is a dual-center retrospective study conducted in two high-volume pericardiectomy centers in China, namely Fuwai Hospital and Chengdu Third People's Hospital. Adult patients diagnosed with constrictive pericarditis and receiving ECMO support after pericardiectomy from January 2011 to May 2023 were included. All procedures within the study complied with the tenets of the Helsinki Declaration. The study was approved and the need for informed consent was waived by the Institutional Review Boards of both Fuwai Hospital (approval No. 2024–2517) and Chengdu Third People's Hospital (approval No. 2023-S-183) owing to the non-interventional and retrospective nature of the study.

All the patients were cannulated with femoral venoarterial-ECMO (VA-ECMO). The indications for post-cardiectomy VA-ECMO aligned with the standard indications for postcardiotomy VA-ECMO: (1) inability to wean from cardiopulmonary bypas (CPB) despite optimal inotropic agents and vasopressor (with or without intra-aortic balloon pump [IABP]). (2) postoperative refractory LCOS and cardiac arrest. Postoperative refractory LCOS was defined as the inability to maintain a systolic blood pressure above 90 mmHg, accompanied by sustained elevated blood lactate levels and signs of hypoperfusion, despite optimized fluid resuscitation, high-dose inotropic support, and vasopressor therapy.

Data was collected from the electronic medical record system, including demographic characteristics, etiology and course of constrictive pericarditis, preoperative status, pericardiectomy surgical information, ECMO details, hospitalization outcomes, and laboratory results and echocardiogram data at different time points. A telephone follow-up was conducted in January 2024.

Literature review

To review the current literature on ECMO use in patients after pericardiectomy, a search was performed in PubMed and Embase on December 4, 2024, using terms such as "ECMO and pericardiectomy","extracorpo real membrane oxygenator and pericardiectomy", "ECLS and pericardiectomy", and "extracorporeal life support and pericardiectomy". A total of 52 articles were retrieved and then 13 duplicated records were removed. The titles and abstracts of the remaining 39 records were screened by two independent reviewers (Bin Jia and Shujie Yan). Twenty-nine records were excluded for irrelevance, 4 were excluded for pre-pericardectomy ECMO use, and 1 was a conference article without a full text. The remaining 5 articles (4 case reports and 1 retrospective study) underwent full-text review and were included for their relevance to ECMO use in patients with constrictive pericarditis after pericardiectomy. (Fig. 1). Data

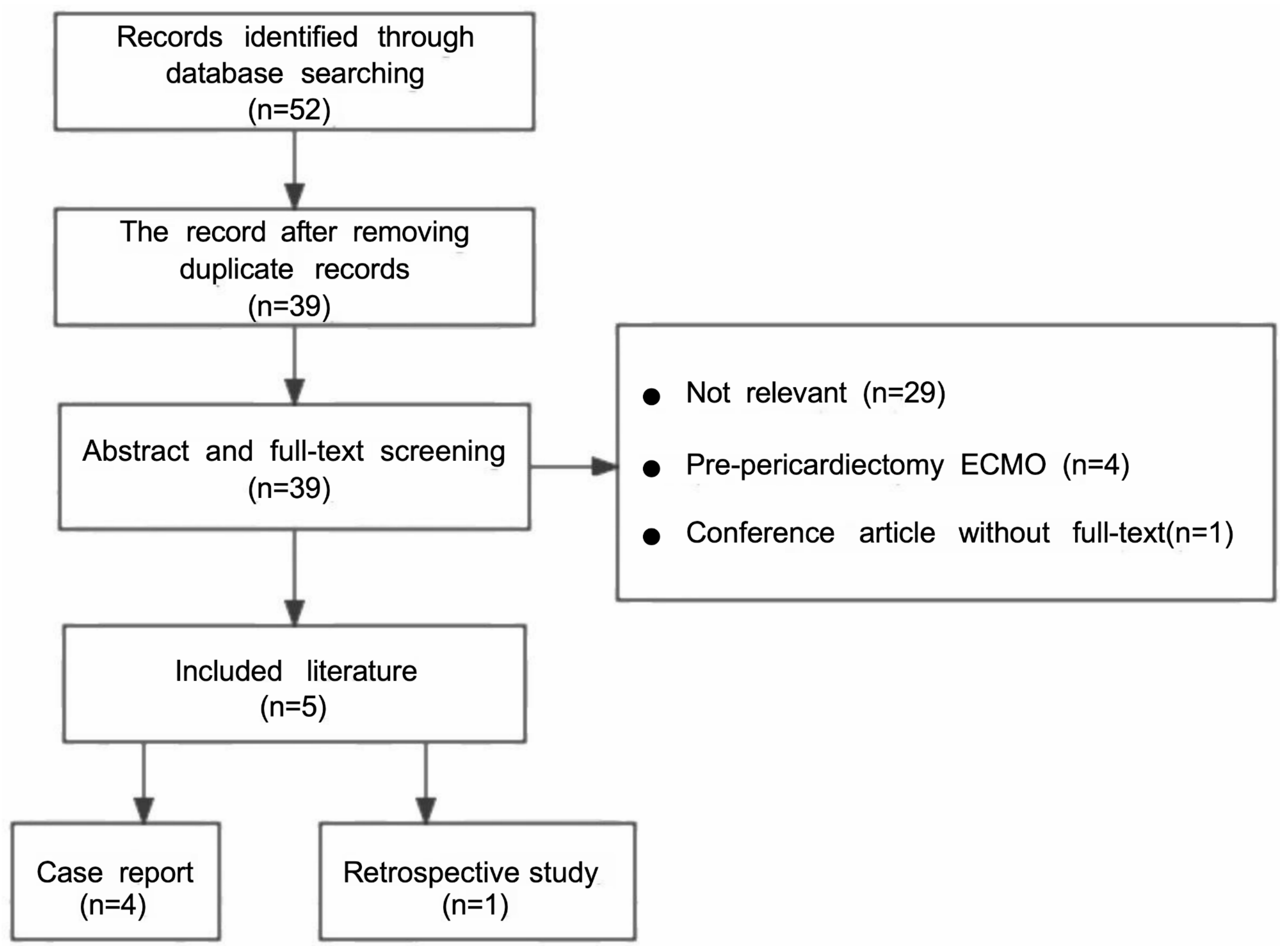

Fig. 1 flow diagram of literature selectin

including patient demographics, surgery-related information, ECMO information, and patient outcomes were extracted from the included literature for analysis.

Results

Case series

Demographic Characteristics and pre-ECMO information Five patients from Fuwai Hospital and four patients from the Third People's Hospital of Chengdu who recieved ECMO support after pericardietomy were included. Four patients was diagnosed with tuberculous constrictive pericarditis, one patient had previous cardiac surgery, and four of them did not had a revalant cause. All the patients had severe heart failure symptoms at baseline. Seven patients were New York Heart Association (NYHA) Functional Classification class III, and 2 patients were NYHA class IV. One patient had a previous history of pericardiectomy 19 years ago (Table 1). Patient No.2,6 and 8 had severe hypoalbuminemia (<30 g/L) (Table 2). All the patients had severely elevated central venous pressure (CVP) of 13–18 mmHg, and accompanied by large or moderate volume of pleural effusion or ascites preoperatively(Table 3). Pericardial calcification was present in seven of the patients.

Surgical procedure Pericardiectomy was performed through a median sternotomy. The operation usually involves stripping the pericardium on the surface of the left ventricle first, and then stripping the pericardium tissues of the right ventricular outflow tract, atrioventricular groove, and the entrances of the superior and inferior vena cava in turn. CPB is used in five patients as concomitant valve repair was performed. (Table 1)

ECMO-Related Information Patient No.9 was transferred from CPB to VA-ECMO due to difficulty in weaning from CPB during surgery. The remaining 8 patients received VA-ECMO support 4–96 h after pericardiectomy due to refractory LCOS (Table 1).Before ECMO initiation, Patients No.2 and No.6 had acute kidney injury (AKI), and Patient No.6 had a significantly elevated aspartate aminotransferase (AST) level, suggesting liver injury. Patients No.4 and No.5 had myocardial injury after surgery with Creatine Kinase-MB(CKMB) significantly ele-

Table 1 Detailed clinical information of the case series

Patient Number (No.)	1	2	3	4	5	6	7	8	9
Demographic Characteristics and preoperatvie information									
Gender/age(y)	M/28	M/28	F/54	M/72	M/20	M/45	F/23	M/33	M/69
Weight(kg)	98	60	67	60	50	65	50	55	69
Pre-op NYHA classification	IV	III	III	IV	III	III	III	III	III
Comorbidities	HTN, CVD, AF, CMP	CVD, AF, CVD, PFO	none	CHD, Severe AS, PIF	CHD, PFO	DM, CVD, AF	AF	AF	HTN, AF, COPD
Etiology	Tuberculosis	idiopathic	idiopathic	idiopathic	idiopathic	Tuberculosis	Tuberculosis	Tuberculosis	post-surgical
Pre-op CVP(mmHg)	17	14	17	15	13	18	16	17	15
Surgical information									
Concomitant procedure	no	MVP, TVP	no	no	MVP TVP	no	MVP, TVP	MVP, TVP	MVP, TVP
re-pericardiectomy	no	yes	no	no	no	no	no	no	no
CPB time (min)utes	no CPB	87	no CPB	no CPB	76	no CPB	73	105	220
ECMO information									
ECMO cannulation time interval after operation(hours)	14	96	50	24	24	4	21	4	from CPB
ECMO running hours (hours)	130	168	192	120	173	190	135	154	166
ECMO cannulation site	femoral	femoral	femoral	femoral	femoral	femoral	femoral	femoral	femoral
Initial ECMO flow (ml/min)	4440	4300	3500	4000	3800	3550	3900	3800	4190
Combine use of CRRT	no	yes	yes	yes	yes	yes	yes	yes	yes
Combine use of IABP	yes	no	no	no	no	yes	yes	yes	yes
ECMO-related complication									
Re-thoracotomy during ECMO	no	no	yes	no	no	yes	no	no	no
RBC Tx during ECMO (U)	0	2	26	14	4	10	2	8	21.5
FFP Tx during ECMO (ml)	0	0	2200	600	400	2000	400	1800	1800
PLT Tx during ECMO (IU)	0	0	2	3	0	1	1	1	1
nadir PLT during ECMO (10^9/L)	47	114	34	31	36	47	43	39	41
nadir Hgb during ECMO (g/L)	97	83	73	81	85	85	89	95	65
ECMO-related thrombus events	no	no	no	no	no	no	no	no	no
ECMO-related lower limb complications	no	no	no	no	no	no	no	no	no
ECMO-circuits related events	no	no	no	no	no	no	no	no	no
In-hospital outcomes									
In-hosptial survival	yes	yes	yes	yes	yes	yes	yes	yes	yes
CPC at hospital discharge	1	1	1	1	1	I	1	1	1
AKI during hospitalization	no	II	II	II	III	I	I	I	II
Stroke during hospitalization	no	no	no	no	no	no	no	no	no
Dialysis requirement at discharge	no	no	no	no	no	no	no	no	no

Table 1 (continued)

Patient Number (No.)	1	2	3	4	5	6	7	8	9
Severe infection during hospitalization	no	no	no	no	no	yes	no	no	no
Mechanical ventilation(hours)	185	109	502	288	184	261	195	231	210
ICU stay(days)	11	13	40	14	16	25	12	11	10
Hospital stay(days)	94	25	59	47	41	94	33	31	34
CVP at discharge (mmHg)	5	4	5	4	5	6	5	5	6
Outcomes at follow-up									
Follow-up duration(months)	32	-	58	148	87	-	21	43	6
Survival at follow-up	yes	-	yes	yes	yes	-	yes	yes	yes

M: Male, F: Demale, NYHA: New York Heart Association, Pre-op: Preoperative; CVP: central venous pressure, HTN: Hypertension, CVD: Cerebrovascular disease, AF: Atrial fibrillation, COPD: Chronic obstructive pulmonary disease, CMP: Cardiomyopathy, DM: Diabetes mellitus, CHD: Coronary heart Disease, AS: Aortic stenosis, PIF: Pulmonary Interstitial Fibrosis, PFO: Patent Foramen Ovale, CHD: Congenital heart disease, MVP: mitral valvuloplasty, TVP: tricuspid valvuloplasty, AVR: aortic valve replacement, ECMO: extracorporeal membrane oxygenation, CPB: cardiopulmonary bypass, Tx: transfusion; RBC: red blood cell, PLT: platelet, FFP: fresh frozen plasma, CRRT: continous renal replacement therapy, IABP: intra-aortic baloon pump; CPC: Cerebral Performance Category, AKI: acute kidney injury, ICU: intensive care unit,

vated. (Table 2). ECMO was instituted via femoral vein and artery cannulation with lower limb cannulation. Heparin anticoagulation was used in all patients with an activated clotting time (ACT) target of 50–80 s. The ECMO flow was maintained at 3500-4500 ml/min, which was proven sufficient as the blood lactate decreased to the normal range within initial 24 h of ECMO support (Table 2). All patients were successfully weaned from ECMO after 120–192 h of ECMO support. No ECMO-related circuit failures, limb ischemia, or thrombotic events were observed during the whole process. However, all patients experienced varying degrees of bleeding complications, and transfusions (including red blood cells, fresh frozen plasma and platelet) were required in 8 cases. Specifically, Patient No. 3, 4, 6, and 9 received transfusions of ten or more units of red blood cells, while Patients No. 3 and 6 underwent re-thoracotomy for surgical hemostasis due to significant bleeding. Four Patients recieved intra-aortic balloon pump (IABP) as a left ventricular unloading measure, and 8 patients received continuous renal replacement therapy (CRRT).

Patient outcomes All patients survived to discharge with good neurological function (Table 1). Patient No. 6 developed pulmonary and wound infections after ECMO decannulation. Microbial cultures of sputum and surgical site tissue revealed the presence of Flavobacterium meningosepticum, Staphylococcus aureus, and Corynebacterium striatum. After implementing optimized antibiotic therapy and wound management stategies, including surgical debridement surgery on the 27th day post-ECMO, the infections were successfully resolved. Patient No.5 had stage III acute kidney injury. The renal function of all patients gradually recovered to the baseline level and no dialysis was required after discharge. At discharge, ultrasound and related examinations showed that the central venous pressure and pericardial thickness were significantly reduced compared with preoperative parameters (Table 3 anFig. . 2). Pleural effusion and ascites almostly disappeared (Table 3). The follow-up results showed that two patients were lost to follow up (No. 2 and 6), Patient No.3 was readmitted twice for coronary artery stent implantation and transcatheter aortic valve implantation respectively. The remaining 6 patients were survived to follow-up without hospital readmissions due to heart failure, pericardiectomy or ECMO-related complications. The mean follow-up interval was 56 months.

Literature review of the cases

Four case reports [3–6] and 1 retrospective study [7] were identified (Table 4). In a retrospective study by Beckmann E [7], 69 patients who underwent pericardiectomy in their center were included. Eight patients received ECMO support due to right heart failure or biventricular heart failure after pericardiectomy, with a hospital mortality rate of 63%. Hasham Ahmad [5] reported a 61-year-old male who prophylactically received VA-ECMO immediately after pericardiectomy without heart failure, providing evidence that the prophylactic application of ECMO may reduce the risk of postoperative heart failure. The other 3 case reports described the use of ECMO in patients with heart failure after pericardiectomy, successfully aiding their recovery. The total mortality of the cases from literature was 41.7% (5/12). Besides, the most frequently reported ECMO-related complication was hemorrage. Three patients underwent re-thoracotomy during ECMO.

Table 2 Laboratory results of the case series

No.	WBC (10^9/L)	TBiL (umol/L)	ALB (g/L)	AST (IU/L)	CREA (μmol/L)	FIB (g/L)	MYO (ng/L)	CKMB (ng/L)	Lac (mmol/L)	PLT (10^9/L)
Preoperative										
1	7.24	57.31	43.6	44	64.35	2.91	10.200	0.615	10.7	196
2	7.52	11.51	22.3	29	85.00	4.29	-	2.04	0.94	214
3	7.81	22.4	42.2	18	96.59	-	-	11	-	188
4	6.97	35.60	40.4	29	107.90	-	-	21	-	124
5	3.84	31.10	42.9	19	57.60	2.98	-	4	-	207
6	5.02	20.9	29.8	25	99	4.27	47.8	1.56	2.0	236
7	4.5	28.2	30.4	32.5	107.9	4.30	< 21.00	10.10	-	238
8	8.8	17.14	26.6	30.5	91.9	4.51	38.71	10.6	-	138
9	5.17	25.1	36.4	28	107	4.04	31.9	5.7	-	116
Before ECMO										
1	11.58	72.82	37.8	30	80.70	5.73	98.78	3.80	4.30	-
2	25.16	18.30	32.2	101	168.185	7.85	602.92	5.64	13.10	255
3	21.33	101.8	37.8	38	81	-	-	4	-	130
4	25.34	41.2	32.3	46	113.60	-	-	75	-	121
5	23.71	-	-	-	79.30	-	-	-	-	289
6	15.17	101.8	37.3	11,099	163	5.6	276	3.77	10.45	-
7	16.21	31.28	30.51	21.63	103.16	4.73	-	3.52	4.81	-
8	14.77	71.17	35.7	186.8	99.4	4.47	-	-	7.46	169
9	-	-	-	-	-	-	-	-	3.87	-
24 h after ECMO initiation										
1	9.48	134.38	36.2	26	67.43	4.74	-	-	2.90	133
2	20.19	47.70	29.4	1009	111.00	17.31	555.54	5.65	1.10	138
3	16.90	130.50	29.0	37	114.80	-	-	18	-	80
4	14.21	72.6	29.5	52	72.2	-	-	-	-	42
5	21.85	74.76	31.3	322	114.20	-	-	215	-	175
6	10.33	92.9	32.6	444	75	62	205.1	-	1.19	222
7	9.64	41.61	29.63	112.69	126.58	-	-	4.73	1.42	-
8	17.57	25.10	33.7	31.9	125.17	4.76	212.50	-	2.65	122
9	10.80	47.6	25.9	63	169	-	178.3	-	1.03	117
Before hospital discharge										
1	7.24	16.01	36.4	27	80.29	3.72	9.070	1.510	0.70	238
2	9.13	13.11	33.3	73	80.15	4.74	-	4.60	1.40	294
3	9.84	26.90	29.4	57	54.8	-	-	-	-	252
4	5.19	34.00	28.8	58	146.89	-	-	0.9	-	98
5	4.81	14.64	48.4	28	77	-	4.61	-	-	264
6	3.68	17.9	32.7	14	38	3.26	-	4.39	1.77	238
7	5.85	38.32	40.4	37.5	62.2	3.19	47.1	3.65	1.10	269
8	5.79	22.58	34.47	34.1	104.3	2.81	-	3.76	1.49	129
9	2.82	48.4	32.8	43	76	4.99	53.6	12.4	-	159

WBC: White blood cell, TBil: total bilirubin, ALB: Albumin, AST: Aspartate Transferase, CREA: Creatinine, FIB: Fibrinogen, MYO: Myoglobin, CKMB: Creatine Kinase-MB, Lac: Lactic acid, PLT: platelet count

Discussion

This study comprehensively analyzed 9 cases from the two high-volume pericardiectomy centers in China and performed a literature review. We found that ECMO support is a crucial and effective rescue method for patients with refractory LCOS after pericardiectomy. The incidence of LCOS after pericardiectomy is 24–28% [7]. The pathogenesis of post-pericardiectomy LCOS is complex. It stems from the sudden increase in preload and excessive dilation of both ventricles beyond the compensatory limit after pericardial decompression, compounded by preoperative myocardial atrophy and cardiac remodeling, as well as myocardial edema and stunning caused by surgical procedures, further impairing cardiac function. This makes it difficult for the heart to adapt to sudden load changes, leading to a crisis of poor systemic perfusion. The key principles of intraoperative and postoperative early management are to restrict fluid and maintain a negative fluid balance to avoid

Table 3 Detailed ultrasound /Echocardiogram data

No.	E/e′	Mitral regurgitation	Tricuspid regurgitation	Pericardial thickness(mm)	Pericardial calcification	Pericardial effusion	Hepatic vein dilation	Septal shudder sign	Ascites	Pleural effusion
Preoperative										
1	8	mild	mild	8	no	a moderate amount	yes	yes	a large amount	a large amount
2	6	moderate	moderate	8	yes	a small amount	yes	yes	a moderate amount	a moderate amount
3	-	no	trivial	6	yes	a small amount	yes	yes	a large amount	a large amount
4	-	mild	no	5	no	a small amount	yes	yes	a moderate amount	a small amount
5	-	trivial	moderate	9	yes	a large amount	yes and severe	yes	a large amount	a small amount
6	4.25	moderate	moderate	10	yes	a small amount	yes	yes	a moderate amount	a large amount
7	13.75	moderate	moderate	10	yes	a small amount	yes	yes	a large amount	a large amount
8	3.2	moderate	moderate	13	yes	a small amount	yes	yes	a large amount	a large amount
9	6.3	mild	mild	9	yes	a small amount	yes	yes	a large amount	a large amount
Before hospital discharge										
1	7	mild	mild	3	no	trivial	yes	no	A small amount	no
2	-	trivial	trivial	4	yes	no	no	no	no	a trace amount
3	-	no	trivial	3	yes	no	no	no	no	no
4	-	trivial	no	2	no	no	no	no	no	no
5	-	no	trivial	3	yes	no	no	no	no	no
6	6.1	no	trivial	4	yes	no	no	no	no	a trace amount
7	7.3	no	trivial	3	yes	no	yes	no	a trace amount	a trace amount
8	4.22	trivial	trivial	4	yes	no	yes	no	no	a trace amount
9	4.1	no	no	3	yes	no	no	no	no	no

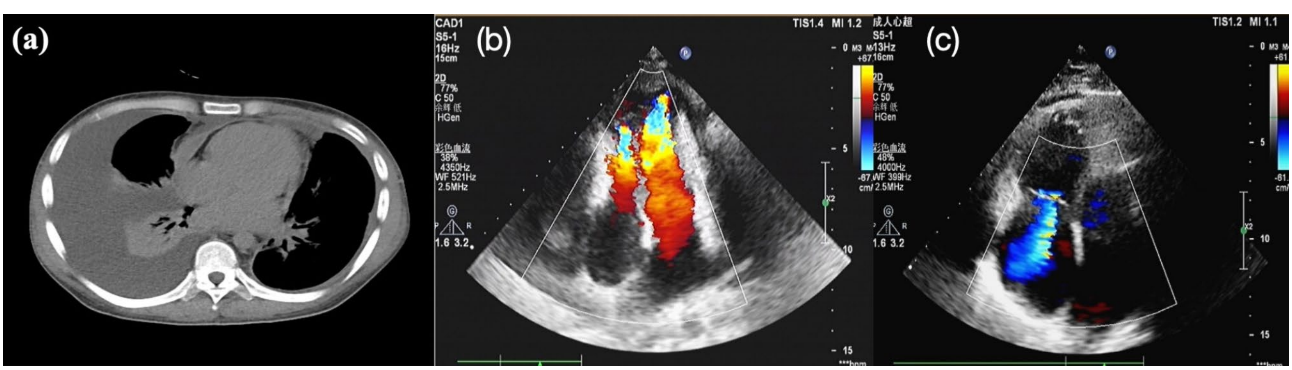

Fig. 2 Images of patient No. 8 **(a)** Pre-operation cardiac CT. **(b)** Pre-operation echocardiography. **(c)** Post-operation echocardiography

right ventricular dilation [8]. This requires a fine balance between cardiac output and intravascular volume, with any deviation potentially leading to serious consequences. For example, excessive fluid retention increases diastolic filling pressure and overstretches myocardial fibers, causing myocardial damage. On the other hand, severe hypovolemia reduces cardiac output and impairs tissue perfusion. In patients with refractory post-pericardiectomy LCOS, VA-ECMO could effectively reduce preload of RV and provide sufficient tissue perfusion. During ECMO support, the remodeled heart by pericardium restraint could gradually adapt to the increased preload, and recovery from surgical-related injury.

Table 4 Cases of post-pericardiectomy ECMO from literature

Year	Author	Demographic Characteristics and Pre-ECMO Information								ECMO-related information							Outcome
		Gender/Age	Etiology	NYHA	CVP (mmHg)	Pericardial calcification	Ascites/ Pleural effusion	pericardial effusion	Surgery	Indication for ECMO	ECMO Timing	ECMO mode	ECMO duration (d)	CRRT	IABP	ECMO-related complications	
2019	Hasham Ahmad [5]	M/61	Idiopathic	-	-	no	-	yes	Pericardiectomy	prophylactically	intraoperation	VA femoral	4	no	no	no	Survival
2015	Karthigesu Aimanan [6]	M/27	Tuberculosis	III-IV	-	no	-	-	Pericardiectomy	Right-sided hear failure	Whith in 24 h after surgery	VA femoral	5	yes	no	no	Survival
2022	Joshua S.Chung [3]	M/48	Idiopathic	IV	4	no	yes	yes	Pericardiectomy under CPB	Heart Dysfunction, Vasoplegia	Whith in 24 h after surgery	VA femoral	7	yes	no	no	Survival
2021	Zhang. Huan [4]	M/66	Tuberculosis	-	-	no	-	-	Pericardiectomy under CPB	Takotsubo Cardiomyopathy	-	-	14	no	yes	no	Survival
2017	Beckmann, Erik [7]	M/60	Tuberculosis	IV	-	-	-	-	pericardiectomy without CPB	Right-sided hear failure	144 h after surgery	VA femoral	4	yes	-	Re-thoracotomy	Death
		M/30	Post-surgical	III-IV	-	-	yes	-	pericardiectomy mitral replacement with CPB	Right-sided hear failure	Whith in 24 h after surgery	VA femoral	2	-	-	Re-thoracotomy	Death
		F/65	Idiopathic	III	-	-	-	-	Subtotal pericardiec- tomy without CPB	Right-sided hear failure	After 24 h	VA femoral	10	yes	-	Cerebral hemorrhage	Death
		M/61	Idiopathic	II	-	-	yes	-	Subtotal pericardiec- tomy without CPB	Right-sided hear failure	After 24 h	VA femoral	11	-	-	no	Survival
		F/24	Idiopathic	III	-	-	-	-	Subtotal pericardiec- tomy without CPB	Right-sided hear failure	After 24 h	Central tube	19	-	-	-	Survival
		F/64	Idiopathic	IV	-	-	yes	-	pericardiectomy, mitral valve replace-ment and tricuspid valve repair with CPB	Biventricular heart failure	Whith in 24 h after surgery	VA femoral	10	yes	-	Re-thoracotomy	Death

Table 4 (continued)

Year	Author	Demographic Characteristics and Pre-ECMO Information								ECMO-related information							Outcome
		Gender/Age	Etiology	NYHA	CVP (mmHg)	Pericardial calcification	Ascites/ Pleural effusion	peri-cardial effusion	Surgery	Indication for ECMO	ECMO Timing	ECMO mode	ECMO duration (d)	CRRT	IABP	ECMO-related complications	
		M/52	Idiopathic	III	-	-	-	-	pericardiectomy with CPB	Right-sided hear failure	48 h after surgery	VA femoral	18	yes	-	no	Survival
		M/45	Idiopathic	-	-	-	-	-	Subtotal pericardiec- tomy, LIMA-LAD bypass without CPB	Right-sided hear failure	96 h after surgery	VA femoral	9	yes	-	no	Death

F: female, M: male, CPB: cardiopulmonary bypass, ECMO: extracorporeal membrane oxygenation, CVP: central venous pressure, VA: venoarterial, CRRT: continous renal replacement therapy, IABP: intra-arterial Baloon pump

The mortality rate in our case series was 0%, which was much lower than that observed following other types of cardiac surgery reported at Fuwai Hospital [9]. This favorable outcome was primarily attributed to the fact that LCOS following pericardiectomy was a reversible process. With VA-ECMO maintaining hemodynamic stability and ensuring adequate cardiac/end-organ perfusion, the cardiac function could gradually recover when the heart regains its compliance and the neurohormonal activation normalized. Other key elements of ECMO management in these patients included: (1) Timely initiation of ECMO before obvious and irrversible end-organ injury. In our case series, except for patient No. 6 and No. 2, all the patients had normal or slightly elevated serum AST, creatinine and CKMB levels before ECMO initiation. (2) Adjuctive IABP to reduce LV load. The marjority of the patients recieved a combined IABP support to counteract the negative effects of ECMO on LV load. (3) Using CRRT to acheive negative fluid balance. CRRT was used in almost all the patients in our case series although only Patient No. 5 developed AKI stage III. The primary aim of the CRRT is to reduce fluid overload and promote successful ECMO weaning. Furthermore, both the two centers were highly specialized in pericardiectomy and ECMO, with a comprehensive understanding of the disease and extensive experience in managing LCOS following pericardiectomy.

Hemorrage was the most frequent ECMO-related complication in the case series from the two centers and literature review. Pericardiectomy itself would cause increased postoperative bleeding due to injury to small epicardial vessles, dense adhensions, and the inherent complexity of the procedue. Anticoagulation and coagulopathy during ECMO further exacerbate the risk of bleeding. Aggressive management of coagulopathy with blood product transfusions (e.g., platelets, fresh frozen plasma) were implemented to restore hemostasis, and surgical re-exploration for hemostasis was indicated when necessary.

All ECMO cases from the two centers involved high-risk patients. Several studies have identified risk factors for worse outcomes after pericardiectomy [10–15], including NYHA class III or IV, preoperative CVP above 15 mmHg, preoperative hypoalbuminemia, preoperative LVEF, preoperative RV dialatation, preoperative liver and kidney injury, pericardium thickness, pericardial calcification, cardiopulmonary bypass and concomitant tricuspid valve repair were reported associated with worse outcomes. The patients in the case series had two to four of the above risk factors. Besides, two patients were NYHA class IV and one pateint underwent a secondary pericardiectomy. We speculated that identification of high-risk patients, early recognition of LCOS and timely ECMO initiation might improve patients outcomes.

Vondran M reported a strategy to initiate ECMO before dissecting the pericardium accompanied by prolonged postoperative weaning in the ICU in high-risk patients could prevent postoperative LCOS and achieve good outcomes [16]. However, the selection of the appropriate patients is difficult. Considering the high cost and potential adverse complications associated with ECMO, we considered a timely initiation of ECMO in post-pericardiectomy patients with LCOS was more feasible, which could also promote good outcomes.

The study had several limitations. The case series of this study was a dual-centric retrospective analysis with a small sample size. The retrospective nature and the lack of control group contributed to a low level of evidence. Furthermore the generalizability of the case reports was constrained, as the cases were from high-volume pericardiectomy centers with highly experienced multiciplinary teams, which might not reflect the outcomes in less specialized setting. Additionally, the literature included in the literature review was mostly case reports, which were susceptible to publication bias and exhibited incosistencies in data quality and interpretation. Therefore, the results of the present study should be interpreted with caution. Future multicenter registry studies and large cohort studies are needed to further clarify the effectiveness, optimal indications, optimal management strategies of post-pericardiectomy ECMO for constrictive pericarditis.

Conclusion

According to the case series and literature review, VA-ECMO might serve as an effective intervention for refractory LCOS following pericardiectomy in patients with constrictive pericarditis. However, due to the limited number of cases, the current evidence remains preliminary. Further studies with larger cohorts and multicenter registry data are needed to confirm the effectiveness of VA-ECMO in this specific patient population. Additionally, future research should focus on identifying optimal timing for ECMO initiation and patient selection criteria to establish high-level evidence for its use in post-pericardiectomy LCOS.

Abbreviations

RV	Right ventricle
LV	Left ventricle
LCOS	Low cardiac output syndrome
VA-ECMO	Venoarterial extracorporeal membrane oxygenation
CPB	Cardiopulmonary bypass
IABP	Intra-aortic balloon pump
NYHA	New York Heart Association
CVP	Central venous pressure
CKMB	Creatine kinase-MB
AKI	Acute kidney injury
AST	Aspartate aminotransferase
ACT	Activated clotting time
CRRT	Continuous renal replacement therapy

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Author contributions
B.J, S.Y, L.G and B.J contributed to the conception and design of the work. B.J, S. Y, Y.L and L.B acquire the data. B.J, S.Y, C.J, C.J and J.W analyze the data. B.J, S.Y, J.F, Y.G and Y.T interpret the data. X.L and G.L prepared Fig. 2. B.J and S.Y drafted the work. Y.L, L.G and B.J revised the work. All authors reviewed the manuscript.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
All procedures within the study complied with the tenets of the Helsinki Declaration. The study was approved and the need for informed consent was waived by the Institutional Review Boards (IRBs) of both Fuwai Hospital (approval No. 2024–2517) and Chengdu Third People's Hospital (approval No. 2023 -S – 183) owing to the non-interventional and retrospective nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Conflict of interest
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