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Echocardiography-Guided Dual-Lumen Venovenous Extracorporeal Membrane Oxygenation Cannula Placement in the ICU-A Retrospective Review

Matthew J. Griffee, MD,
Department of Anesthesiology

Joshua M. Zimmerman, MD, FASE,
Department of Anesthesiology

Stephen H. McKellar, MD, MSc,
Division of Cardiothoracic Surgery

Joseph E Tonna, MD
Division of Emergency Medicine

Division of Cardiothoracic Surgery

Department of Surgery

INTRODUCTION

Despite controversy regarding patient selection and clinical efficacy, venovenous extracorporeal membrane oxygenation (VV ECMO) use for severe respiratory failure is increasing. [1–3] Potential advantages of VV ECMO over conventional support include the reduction of airway pressures and sedation, early patient mobilization, and reduced time to extubation.[4–12] However, early mobilization and extubation can only be achieved if femoral cannula placement is avoided. This can be done by using a dual lumen, single cannula in the internal jugular (IJ) position.

The dual lumen cannula for VV ECMO has multiple drainage orifices in the superior vena cava and inferior vena cava (IVC) and a return limb directing blood across the tricuspid valve.[7,12] The cannula traverses the right atrium (RA), and its terminal tip resides 3–5 cm within the IVC (Figure 1).[13] Approaches to cannulation and complications with placement have been reported, including perforation of the great vessels or right ventricle, which may prove fatal.[7,14–20] Fluoroscopy can be used to visualize the wire traversing the right atrium and entering the IVC before advancement of the cannula.[19–20] The need for fluoroscopic guidance in a hybrid operating room or catheterization lab may delay cannulation. Furthermore, it may be dangerous to transport patients who are hemodynamically unstable and dependent on high ventilator settings.

Corresponding Author: Matthew Griffee, MD, Department of Anesthesiology, University of Utah School of Medicine, Matthew.griffee@hsc.utah.edu,30 N Medical Drive, Rm 3C444, Salt Lake City, Utah 84132-2101, Fax: 801-581-4367.

Alternative options to fluoroscopy guidance in an interventional suite include portable X-ray and blind placement. Portable x-ray images in intensive care unit (ICU) rooms have quality limitations. Blind placement of a large cannula is problematic because of the need to separate venous drainage (predominantly from the IVC) and return flow (directed to the tricuspid valve) with precise cannula positioning.[21,22] Echocardiographic guidance, either alone or accompanied by fluoroscopy, has been described as an alternative to fluoroscopic guidance in an operating room or interventional suite.[15,23–25]

The authors previously have described their standard institutional practice of placing the dual-lumen single VV ECMO cannula using transesophageal echocardiography (TEE) during cannulation in the ICU.[26] In this companion article, the authors summarize analysis of a consecutive case series of VV ECMO cases to determine the success rate of initial cannulation as well as the frequency of subsequent cannula adjustment, and to illustrate common cannula malposition examples diagnosed by echocardiography.

MATERIALS AND METHODS

DATA SHARING

To facilitate research reproducibility, replicability, accuracy and transparency, the datasets generated and/or analyzed during the current study, and the associated analytic code, will be made available indefinitely, following publication, to anyone who wishes to access the data for analysis, on the Open Science Foundation[29] (OSF) repository under DOI 10.17605/OSF.IO/KRGF2 at https://osf.io/krgf2/. Data were de-identified in accordance with Section 164.514 of the Health Insurance Portability and Accountability Act.

Study Design—This is a retrospective, observational cohort study of sequential patients managed with VV ECMO at a single tertiary care center that accepts regional referrals for respiratory failure. After Institutional Review Board approval (#104589), two internal institutional databases were queried to identify and cross-check all cases of VV ECMO managed from 2012 to 2018. Data was extracted from the electronic medical record directly into REDCap[27] by a trained research coordinator, and directly into an Excel spreadsheet by a trained ECMO coordinator, respectively. Subsequent chart review was performed by the investigators to obtain additional information regarding complications.

Participants—Inclusion criteria included adult or pediatric patients who underwent placement of ECMO in the venovenous configuration, with the dual lumen cannula, for respiratory failure. Exclusion criteria included cannulation at a referring hospital by surgeons who do not use echo guidance in the ICU, insufficient documentation, and cannulation for veno-arterial ECMO.

Covariates and Outcomes—Covariates included: age (years), weight (kilograms), height (centimeters), body mass index (km/m^2), sex, cannula size (French, Fr), number and details of each documented echocardiogram (including type of echocardiogram (transesophageal vs transthoracic)), ventricular function at initial placement (right and left ventricular systolic function), cannula position (acceptable vs. problematic location), hemodynamic assessment at the time of study (based on documentation of hypotension or cardiac arrest), clinical interventions necessary to treat instability at the time of study, clinical complications at the time of the echocardiogram, clinical complications from cannulation procedure, cannula adjustment, consequences from subsequent cannula position (after initial placement), duration of ECMO (days), vital status at decannulation, discharge disposition location, and cause of death.

An adequate outflow jet was defined as a turbulent jet visualized by color flow Doppler in the right atrium, originating from the outflow spout, with flow directed towards the tricuspid valve. This was either documented in the medical record at the time of initial imaging, or was determined by review of the video clips. We assessed the following patient and cannulation characteristics for association with the outcome of successful decannulation: age, procedure location (ICU vs other), right and left ventricular function at cannulation, initial cannula position, complications of initial cannulation procedure, consequences of initial cannula malposition, and need for cannula adjustment.

Statistical Analysis—Descriptive statistics, including median (interquartile range; IQR), were used to assess patient characteristics. Categorical characteristics were compared using Fisher exact test and ordinal variables with the use of the Wilcoxon-Mann-Whitney test. Continuous characteristics were compared using independent samples t-test. Coefficients, 95% CI's and *p*-values were reported from all models. Statistical analyses were conducted in STATA 15.1. Significance was assessed at the 0.05 level and all tests were two-tailed.

RESULTS

Study Population

From 2012 to 2018, 48 sequential cases of VV ECMO were identified. Three cases were excluded because cannulation had been performed at referring hospitals, and initial cannula position success and any complications of cannulation were unknown. Our final cohort included 45 cases.

Patient Characteristics

Patient characteristics are described in Table 1. Age ranged from 10–75 years (Median 35; Interquartile Range [IQR] 25, 58), 71% were male. The most common causes of respiratory failure were pneumonia, aspiration, or inhalational burn injury. Cannulas ranged from 20–31 Fr; 53% were 27Fr. ECMO duration was 10 (5, 17) days, with the longest run 70 days. Thirty patients (67%) survived to decannulation and 28 (62%) survived to discharge, including 11 patients who were discharged directly to home. (Table 2).

Echocardiography

Transesophageal echocardiography (TEE), without fluoroscopy, was performed in 42 (93%) of cases to guide cannulation. Two patients (4%) had contraindications to TEE: one had undergone esophagectomy, and another had had a recent gastric bypass. In these cases, transthoracic echocardiography (TTE) was used in combination with fluoroscopy in the ICU. Forty cases (89%) were performed in the intensive care unit (ICU) and four were in the operating room. In the single case performed in the cath lab, TEE guidance was used along with fluoroscopy. The total number of echo studies reported for both cannulation and subsequent re-evaluation of cannula position was one or two in 34 cases (76%); seven patients (16%) required >3 echo studies (Figure 2). At the time of cannulation, right ventricular systolic function was normal in 32 patients (73%) and abnormal in 12 (27%). Left ventricular systolic function was normal in 28 patients (65%), hyperdynamic in 2 (5%), and abnormal in 13 (30%) (Table 1). RV function could not be interpreted because of inadequate clips in one case, and LV function could not be interpreted because of inadequate clips in two cases.

Successful Positioning and Adverse Events at Initial Cannulation

Adverse events during cannulation occurred in 12 cases (27 %) (Table 3). Six adverse events were directly associated with cannulation problems (for an incidence of 13%). The first was a vascular injury (described below). The cannulation in this case was successful when a smaller cannula was used. There were two cases of inadvertent cannula position in the RV, resulting in persistent hypoxemia in both cases, as well as recurrent supraventricular tachycardia in one case. There were two cases of persistent hypoxemia from cannula outflow located in the IVC, and one case of a cannula tip becoming kinked in the right atrium. Finally, for one patient, attempts to cannulate were aborted due to the finding of internal jugular thrombosis. Thus, initial cannulation was successful in 39 of 45 cases (87%), with five cases of initial malposition of the cannula and one aborted attempt. The unacceptable locations were right ventricle (two cases), too deep (two cases) and one case of a hairpin bend of the cannula in the right atrium (Table 3).

Of the four cases with a complication of cardiac arrest, in no case was the arrest related directly to the cannulation procedure. Three of the four cases of cardiac arrest peri-cannulation resulted in prompt return of spontaneous circulation after a brief period of chest compressions, and an ultimate outcome of survival to discharge (Table 3B). In the fourth case, the cardiac arrest during cannulation was in the context of multi-system organ failure, and there was persistent shock despite mechanical circulatory support. Further efforts were suspended within hours of cannulation because they were judged to be futile. Finally, there was one case of severe hypotension at the time of cannulation, necessitating vasopressors and fluid challenge (Table 3B).

The most serious adverse event was vascular injury, bleeding, and hemorrhagic shock in a 19-year-old male with a BMI of 19.5kg/m^2 and body surface area (BSA) of 1.67m^2. The initial attempt to place a 27 Fr cannula failed, as the cannula could not be advanced beyond the superior vena cava/right atrial (SVC/RA) junction. The metal reinforcements became enmeshed in the endothelial lining of the SVC, and removal of the cannula was difficult, necessitating a second operator. A 23 Fr cannula was then placed successfully. On inspection of the 27Fr cannula, the outside wire frame was noted to have bent components, and this area was covered by a sheath of vascular tissue, consistent with an intimal venous degloving injury. During the procedure, the patient became hemodynamically unstable and TEE revealed a new pericardial effusion, without evidence of tamponade (Video Clip 1). The hypotension and bleeding necessitated transfusion of 4 units of packed red blood cells before achieving hemodynamic stability. Pericardial drainage was not necessary. After several days of VV ECMO, the patient required conversion to veno-arterial ECMO because of right ventricular failure and persistent hypoxemia. Ultimately the patient had 65 days of ECMO support and underwent lung transplantation.

One case of malposition of the cannula into the RV was associated with atrial fibrillation and multiple cardioversions, as well as an effusion adjacent to the RV, but without clinical tamponade (Video Clip 2). Low flow was present until the cannula was repositioned. In the other case of malposition of the cannula with tip in the RV, persistent hypoxemia lead to repeat TEE, and the cannula tip was repositioned in the IVC, with immediate improvement in oxygenation.

In three cases, the long, thin, flexible guidewire bent either during dilation in the neck or from repeatedly catching on the Eustachian valve (along the anterior IVC-RA junction). In two of these cases, the patients were obese (BMI 42kg/m^2 and 36.6 kg/m^2). The situation was addressed in two cases by placing a sheath over the first guidewire, and then advancing a stiffer wire which facilitated Seldinger technique for placement of the distal tip into the IVC. In a third case, a malleable angled wire was used to replace a guidewire with a loop in the RA, so that the guidewire tip could be positioned in the IVC.

There was a single case of aborted cannulation, which was due to a right IJ thrombus. The patient had completed 30 days of ECMO for ARDS and was initially stable after decannulation. However, within a few hours, the patient developed pulmonary edema associated with hypoxemic respiratory failure. Efforts were made to re-access the right IJ for additional ECMO support, but the cannulation attempt was aborted because significant right IJ thrombus was identified. The patient was successfully treated with mechanical ventilation (and without a second run of ECMO) and was discharged to home.

Echocardiographic Evaluation of Cannula Position

During the course of VV ECMO support, echocardiography may be needed to evaluate cannula position when there are clinical signs suggesting malposition, such as hypoxemia, line chatter, low flow, or suck down events. In our cohort, 17 patients (38%) had echocardiographic identification of malposition of the cannula during the ECMO run (Figure 2). The most common cannula position found in hypoxemic patients was too shallow. Other problematic positions were too deep, malrotated, or tip in hepatic vein. The most common intervention was to change the depth or rotate the cannula. Figure 1 illustrates the types of malposition identified by echocardiography and the number of cases of each malposition type. Some patients required multiple echo-guided cannula adjustments (Figure 2).

Association between characteristics and survival

Associations between patient and cannulation characteristics and survival to decannulation are reported in Table 4. Younger age (36 vs 52 years; $p<0.01$) was the only characteristic associated with survival. There was no significant association between cannula malposition and survival to decannulation. There was no significant association between the need to adjust the cannula during ECMO and survival (Table 4).

DISCUSSION

In our series, we observed that 39/45 or 87% of cannulations resulted in an initial proper position of the cannula. Nevertheless, a cardinal finding of the case series is that despite high initial success in cannula positioning, 38% of patients required echo-guided cannula adjustments during the course of ECMO. The precise positioning and orientation of the cannula needed for efficient separation of drainage and return flow leads to clinically significant oxygenation problems for many patients. A step-by-step approach to troubleshooting hypoxemia and cannula malposition during ECMO is presented in Figure 3.

Even with echocardiographic guidance, the cannula tip was inadvertently positioned (or migrated soon after cannulation) into the right ventricle in 2 cases (4%). This potentially catastrophic consequence is important to recognize, as blind advancement in the right ventricle can cause RV perforation. ECMO oxygenation was inadequate because of recirculation. Fortunately, no injuries to the right ventricle were evident in our series.

The guidewire may bend—or even loop—at the level of the IVC/RA junction when the Eustachian valve is prominent, or when there is an angle between the inferior RA and IVC. This bend in the guidewire then directs the cannula tip anteriorly as it is advanced through the right atrium, which can subsequently catch on the Eustachian valve (Video Clip 3, Video Clip 4). Efforts to advance the cannula when the tip has engaged the Eustachian valve reinforce the anterior curve of the wire and cannula tip.

It may be prudent to take extra steps to control the tip of the guidewire and cannula when there is a large Eustachian valve and/or prominent angulation between the IVC and RA. For example, a small caliber dilator can be placed over the initial wire to allow safe advancement of a stiffer wire so that the guidewire position crossing the RA and ending deep in the IVC follows a straight course. An alternative strategy is to place a catheter with an angled tip over-the-wire.

While our series primarily utilized TEE, we have noted that TTE is complementary and sometimes superior to TEE for cannula assessment. The lower esophageal sphincter can cause shadowing of the inferior RA/IVC junction, and a subcostal TTE view of this area may be more informative than the TEE bicaval or transgastric views focused on the right atrium. In one case, it was difficult to demonstrate that the cannula tip was in the RV by TEE, but obvious using TTE (Video Clips 5–7). A second TEE was carried out with more attention directed to looking at the transgastric RV inflow from multiplane angles to interrogate the posterior aspect of the tricuspid valve, which revealed the cannula clearly crossing from the RA into the RV (Video Clip 2). Additional structures which may be imaged more easily by subcostal TTE than by TEE include the hepatic vein and the IVC distal to the hepatic vein (particularly if transgastric TEE views are limited). When the distal cannula is not visible in the IVC, the parasternal RV inflow view may prove to be useful to evaluate whether the tip is in the RV (Video Clip 8).

Other investigators have reported complications encountered during TEE guidance for placement of the dual lumen single cannula. In a large survey study from France, TEE guidance was used in 35 of 52 total cases.[15] In this study, complications included 2 patients with myocardial perforation (4%), one of whom died (2%). This is comparable to our observed rate of great vessel trauma (2%), though the imaging modality for the two patients in that study was not reported. In the Conrad study of 190 percutaneous cannulations, only 15 were the dual lumen cannula, and nearly all VV ECMO cases involved fluoroscopic guidance.[28] They reported a low complication rate, which included one great vessel perforation during adult VV ECMO performed under fluoroscopic (but not ultrasound) guidance (1/63 patients; 2%). A study of 720 patients who underwent percutaneous cannulation for ECMO included 76 patients who received the dual-lumen cannula, but complications and placement technique for this subset were not reported separately.[17]

Fluoroscopic guidance has been recommended to diagnose malposition during placement and to prevent complications.[28] In our series, acceptable positioning was achieved in 87% of patients, with 93% of procedures guided by TEE without fluoroscopy. Serious consequences of vessel or myocardial perforation were comparable to those reported from two large studies reporting outcomes, one of which utilized fluoroscopic guidance. Some considerations in favor of echo guidance include the ability to evaluate RV and LV systolic function, tricuspid regurgitation, and pericardial effusions, the avoidance of radiation, and the portability of echo machines. Considerations in favor of fluoroscopy include identification of wire position without respect to the angulation or plane of the wire, and a wider variety of angled and stiff wires and introducers are available in the cath lab or hybrid operating room interventional suite.

Limitations and Future Directions

Limitations of this study include absence of a comparable cohort of patients undergoing fluoroscopy for a direct comparison of the safety and effectiveness of TEE-guided cannulation in the ICU. Other limitations include small case volume and a single site. For serious but rare complications, a much larger population of patients undergoing VV ECMO would be needed to provide robust estimates of the risks. Because there was no prospective surveillance of all patients for cannula malposition, it is possible that the documented cases of problematic cannula position underrepresent the actual number. However, it seems likely that clinically relevant cannula malposition was detected in the majority of cases, because the dual lumen cannula only works for patients with severe lung injury when return flow and venous drainage have a very specific location and orientation in the RA and IVC.

We elected to include two patients who had contraindications to TEE, four patients cannulated in the OR, and one patient cannulated in the cath lab, because our interest was to define not only the initial success of cannula placement (87%), but also to describe how often the cannula was adjusted during the course of ECMO (38%).

CONCLUSIONS

Cannulation for VV ECMO using the dual-lumen bicaval cannula is feasible using TEE guidance in the ICU. Persistent hypoxemia and low flow may indicate cannula malposition. The need to reposition the cannula during the ECMO run is common. TEE can be helpful in diagnosis of cannula malposition and to guide repositioning. More research is needed to determine the relative risks, costs, and outcomes of different cannulation strategies and different image guidance techniques for VV ECMO.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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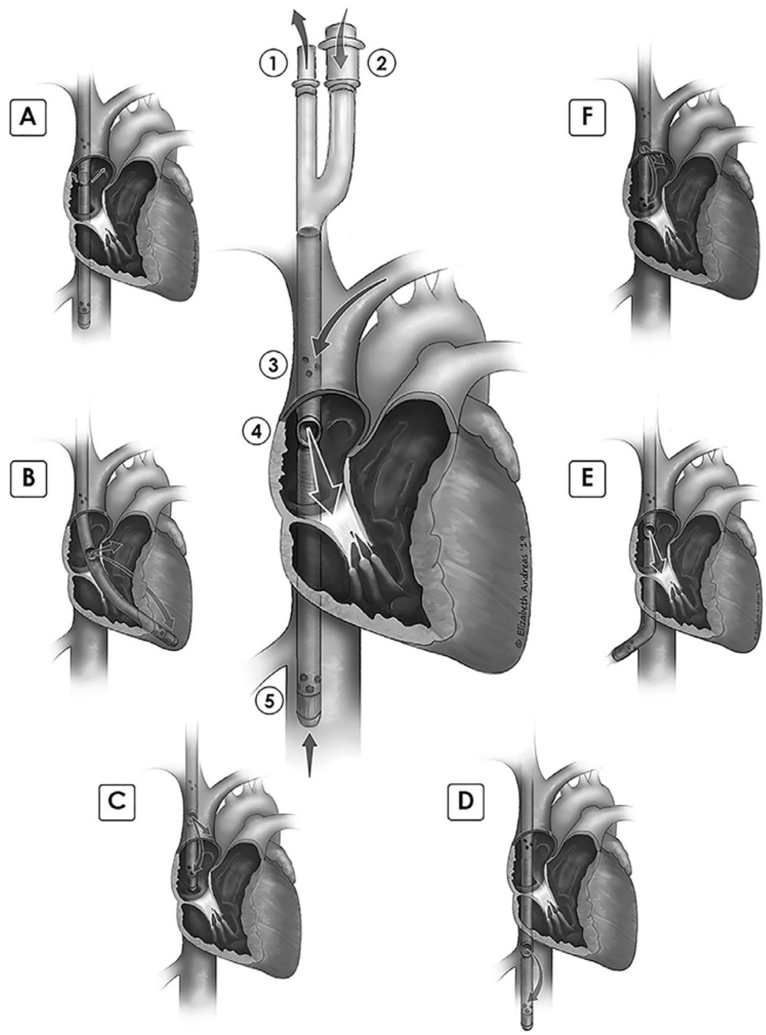

Figure 1: Cannula correct position and malposition illustrations

Central figure: proper cannula depth and orientation. 1. Bicaval drainage outflow limb. 2. Post-oxygenator return limb. 3. Superior vena cava drainage orifices. 4. Return flow spout, at level of upper fossa ovalis, return jet directed anteriorly, towards center of tricuspid valve. 5. Inferior vena cava drainage orifices, with distal tip located a few centimeters beyond hepatic vein. Malposition illustrations and case numbers: A. Return flow oriented away from tricuspid, jet directed posteriorly, towards interatrial septum- 4 cases. B. Cannula within right ventricle, return flow recirculating by entering distal drainage orifices. Tip is against distal RV lateral wall- 2 cases. C. Distal tip of cannula in right atrium, too shallow. Return flow jet within SVC, likely not visible by TEE. Recirculation of flow from return jet into distal drain orifices- 6 cases. D. Cannula too deep, return flow within IVC, recirculation into distal drainage orifices- 7 cases. E. Tip in hepatic vein. Vein may collapse around distal drainage orifices, leading to chatter and low flow alarms in ECMO circuit- 6 cases. F. Return flow at upper RA/SVC junction, leading to recirculation of flow with some return flow entering distal orifices; distal tip is near RA/IVC junction; note that return flow may be seen with TEE- 3 cases.

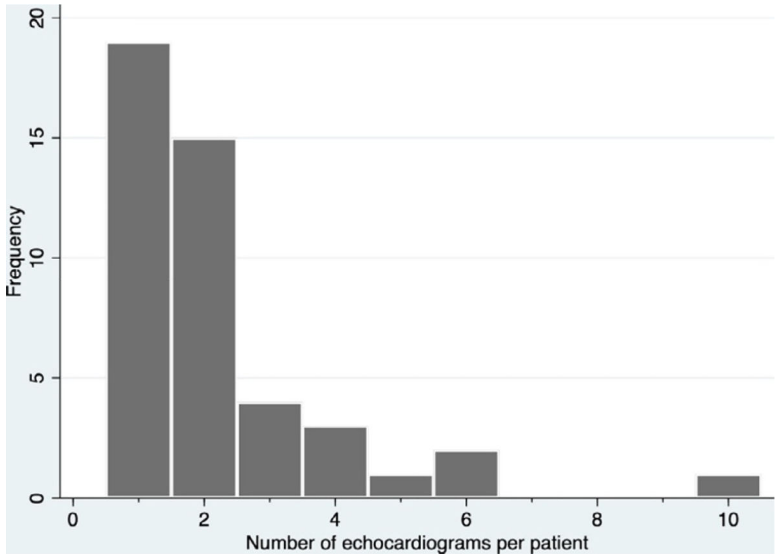

Figure 2:
Frequency of echocardiography studies per patient

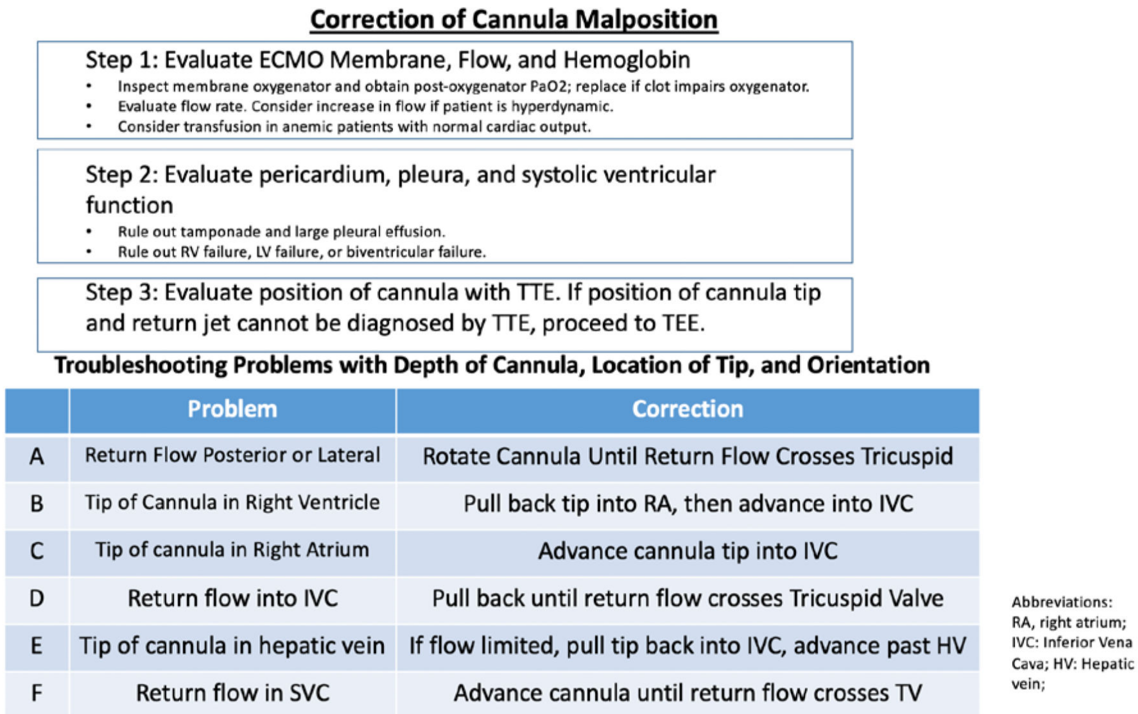

Fig 3.

Stepwise approach to troubleshooting persistent hypoxemia during VV ECMO.

Table 1:

Baseline characteristics of patients

Variable	**n (%)**
Age* (years)	35 (25, 58)
BMI* (kg/m^2)	32 (24, 38)
Height* (cm)	173 (165, 179)
Weight* (kg)	88 (69, 118)
Female Sex	13 (29%)
Cannula Size	
20	1 (3%)
23	4 (10%)
27	21 (53%)
31	14 (35%)
Duration of ECMO in Days*	10 (5, 17)
Total number of echocardiography studies per patient during ECMO for cannula position*	2 (1, 2)
Clinical Presentation	
ARDS	31 (69%)
Burn/Inhalation Injury	7 (16%)
Bacterial Pneumonia	5 (11%)
Viral Pneumonia	12 (27%)
Aspiration	6 (13%)
Not Specified	1 (2%)
Perioperative/Cardiogenic	7 (16%)
Protein Alveolar Proteinosis	2 (4%)
Trauma	1 (2%)
Interstitial Lung Disease	1 (2%)
Post-transplant	3 (7%)
RV function at placement	
Normal	32 (73%)
Abnormal	12 (27%)
LV function at placement	
Normal	28 (65%)
Hyperdynamic	2 (5%)
Mildly reduced	8 (19%)
Moderate dysfunction	3 (7%)
Severe dysfunction	2 (5%)

*Median (interquartile range, IQR)

Missing values by group: BMI=1/45, Height=1/45, Weight=1/45, Cannula size=5/45, RV function at placement=1/45, LV function at placement=2/45

Table 2:

Cannula position and complications (n=45 patients)

Variable	n (%)
Complications (*any*)	12 (27%)
Cardiac arrest	4 (9%)
Pericardial hemorrhage	1 (2%)
Unable to cannulate/aborted	1 (2%)
Hypotension	1 (2%)
Cannula malposition	5 (11%)
Complications (*due to procedure*)(*any*)	6 (13%)
Pericardial hemorrhage	1 (2%)
Unable to cannulate/aborted	1 (2%)
Cannula malposition	5 (11%)
Clinical consequences of initial malposition (n=44)	
Not Applicable	39 (89%)
Hypoxemia	4 (9%)
Decreased Flow	1 (2%)
Cannulation location	
ICU	40 (89%)
Cath Lab	1 (2%)
Operating Room	4 (9%)
Imaging used for cannulation	
TEE	42 (93.3%)
TTE + Fluoroscopy	2 (4.4%)
TEE + Fluoroscopy	1 (2.2%)
Clinical consequences of malposition later during ECMO course	
None	27 (61%)
Hypoxemia	13 (30%)
Decreased Flow	3 (7%)
Insufficient documentation	1 (2%)
Cannula adjusted during ECMO run	21 (47%)
Survived to successful decannulation	30 (67%)
Disposition among those successfully decannulated from ECMO (n=30)	
Home	11 (37%)
Long-Term Acute Care	7 (23%)
Acute Rehabilitation	9 (30%)
Transfer to another hospital	1 (3%)
Died before discharge	2 (7%)
Cause of death on ECMO (*n=15*)	
Multi-system organ failure	5 (33%)
Transition to palliative care	3 (20%)
Neurologic injury	5 (33%)

Variable	n (%)
Other	2 (13%)
Cause of in-hospital death after ECMO (*n=2*)	
Hypoxemia/hypercarbia	1 (50%)
Cardiogenic shock	1 (50%)

Missing values by group: Complications (due to procedure)=1/6; Clinical consequences of initial malposition=1/44; Clinical consequences of malposition later during ECMO course=1/44; Disposition among those successfully decannulated from ECLS=1/30

Table 3A:

Adverse Events At Time of Cannulation Attributed to Procedure (6/45)

Complication	Intervention	Outcome
Pericardial hemorrhage due to SVC Degloving Injury	Smaller cannula used on successful second attempt; four unit blood transfusion	Survived ECMO to lung transplant
Cannula displaced into RV, decreased flow, persistent hypoxemia and tachyarrhythmia	Repositioned cannula under echo guidance	Transitioned to palliative care after hemorrhagic stroke
Cannula displaced into RV, persistent hypoxemia	Repositioned cannula under echo guidance	Discharged home
Cannula too deep, outflow in IVC, persistent hypoxemia	Repositioned cannula under echo guidance	Discharged to LTAC, then to home
Cannula too deep, outflow in IVC, persistent hypoxemia	Repositioned cannula under echo guidance	Discharged home
Cannula too shallow, kinked in right atrium, persistent hypoxemia	Repositioned cannula under echo guidance	Discharged to acute rehab, then to home

Table 3B:

Adverse Events At Time of Cannulation Due to Patient Condition

Complication	Intervention	Outcome
Internal Jugular Discovered to be thrombosed	Procedure aborted	Managed with mechanical ventilation; survived to discharge
Cardiac arrest	Pressors, ACLS, VA ECMO	Support withdrawn due to futility
Cardiac arrest	Brief chest compressions	Discharged to LTAC
Cardiac arrest	Brief chest compressions	Discharged home
Cardiac arrest	Brief chest compressions	Discharged home
Hypotension	Vasopressors and fluids	Discharged to LTAC

Abbreviations

SVC, superior vena cava; RV, right ventricle; IVC, inferior vena cava; LTAC, long-term acute care facility

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Table 4:

Univariate associations with survival

Variable*	**Dead (n=15)**	**Alive (n=30)**	***p*-value**
Age†	52.3 ± 4.7	35.6 ± 3.0	<0.01
Cannulation Site			0.45
ICU	14 (93.3%)	26 (86.7%)	
Cath lab	1 (6.7%)	0 (0.0%)	
OR	0 (0.0%)	4 (13.3%)	
Right ventricle function			1.0
Normal	11 (73.3%)	21 (72.4%)	
Abnormal	4 (26.7%)	8 (27.6%)	
Complications during procedure	2 (13.3%)	8 (26.7%)	0.46
Complications due to cannulation	1 (6.7%)	4 (13.3%)	0.65
Cannula adjustment	7 (46.7%)	14 (46.7%)	1.00
Consequences of initial malposition			0.05
Hypoxemia	0 (0%)	4 (14.3%)	
Decreased Flow	1 (6.7%)	0 (0%)	
None	14 (93.3%)	24 (85.7%)	
Consequences of subsequent malposition			0.66
Hypoxemia	5 (33.3%)	8 (27.6%)	
Decreased flow	0 (0%)	3 (10.3%)	
Insufficient document	1 (6.7%)	0 (0%)	
None	9 (60%)	18 (62.1%)	

*Number (percent)

†Mean ± Standard Error

Abbreviations: ICU, intensive care unit; Cath lab, catheterization laboratory; OR, operating room

Missing values by group: RV Function=1/45; Consequences of initial malposition=1/44; Consequences of subsequent malposition=1/44