Bicaval dual lumen cannula placement using transthoracic echocardiography in COVID-19 scenario: pearls and pitfalls

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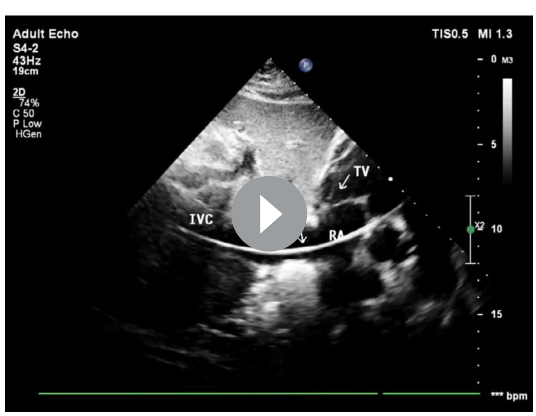
SUMMARY

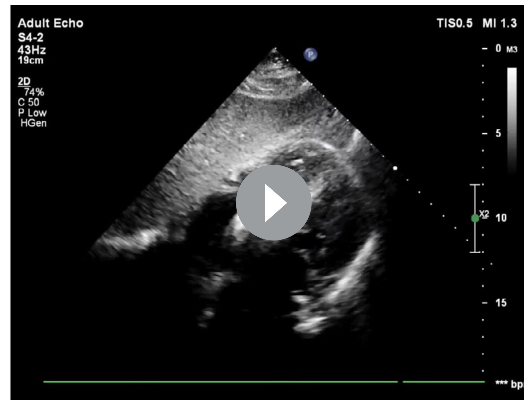
A woman in her 50s who had been diagnosed with COVID-19 developed deep vein thrombosis in the left femoral vein extending into inferior vena cava (IVC). An IVC filter was placed to prevent fatal pulmonary embolism. Her respiratory failure subsequently deteriorated despite optimal mechanical ventilation and required venovenous extracorporeal membrane oxygenation (VV-ECMO) as a rescue therapy. Femoro-jugular VV-ECMO configuration was not suitable due to the IVC filter, hence a single-site venous cannulation using bicaval dual lumen (AvalonElite) cannula was selected. Placement of the Avalon cannula conventionally requires guidance by fluoroscopy or transoesophageal echocardiography, which were not feasible in COVID-19 patients. Hence, transthoracic echocardiography guidance was chosen. Guidewire looping into the right ventricle might lead to cannula malposition and imminent right ventricular rupture, but these could be detected by 'bending' sign. Transthoracic echocardiography could be a feasible guidance method for Avalon cannulation, nonetheless a thorough protocol should be followed to avoid cannula malposition during the procedure.

BACKGROUND

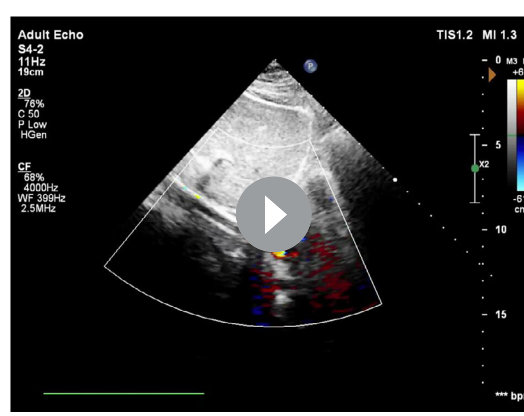
Venovenous extracorporeal membrane oxygenation (VV-ECMO) is used as a bridging therapy for patients with severe hypoxaemic respiratory failure refractory to optimal mechanical ventilation, including COVID-19 patients.[1,2] The sites of venous drainage of deoxygenated blood and return of oxygenated blood should be separated to avoid recirculation phenomenon. In conventional VV-ECMO, femorojugular approach is preferred for vascular cannulation with the drainage cannula inserted via femoral vein and threaded up until its distal tip is 1–2 cm below the cavoatrial junction to avoid inferior vena cava (IVC) collapse due to high-flow cannula suction effect,[3] and the return cannula inserted preferably into the right internal jugular vein (IJV). The appropriate landmark of



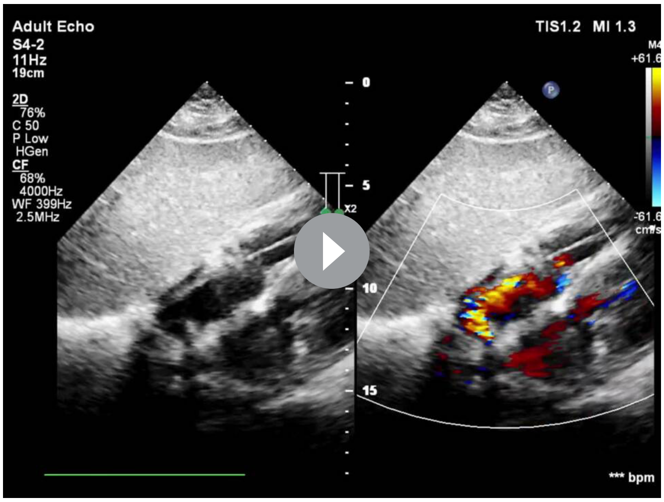
Video 1 Correct position of the distal guidewire in the IVC was confirmed by subcostal longitudinal TTE view. note that the cephalad portion of the guidewire was next to the aortic valve, having passed through the tricuspid valve to the lower portion of the right ventricular outflow tract. this sign was overlooked during the procedure.



Video 2 Subcostal four-chamber TTE view revealed the tip of the cannula was advanced to the apex of the right ventricle. The cannula was immediately retracted into the right atrium due to anticipated risk of right ventricular perforation.



Video 3 Subcostal bicaval view showed the distal part of the Avalon cannula advanced too deeply into the IVC, with the aliasing signal of blood flow emanating from the returning middle port.



Video 4 Subcostal four-chamber view revealed an aberrant flow emitting from the returning middle port towards the right atrial free wall.

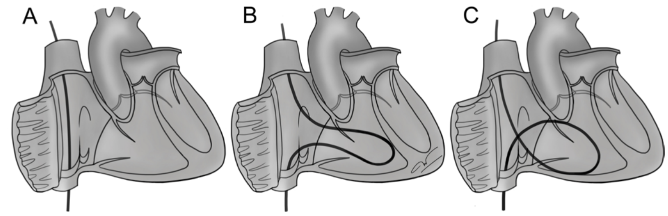


Figure 1 Illustration of how the guidewire migrates across the tricuspid valve into the right ventricle despite its proximal and distal parts remaining in the SVC and IVC, respectively. Note that the guidewire portion just cephalad to the IVC ostium is bent towards either the inferior part of the tricuspid ostium (B) or the superior part of the tricuspid ostium near the aortic valve (C), compared with the correct straight longitudinal trajectory of the guidewire (A). This 'bending' can be detected by observing meticulously the entire intracardiac portion of the guidewire on subcostal views of TTE (video 1) (illutrastrated by Ngoc Minh Le). IVC, inferior vena cava; SVC, superior vena cava; TTE, transthoracic echocardiography.

the return cannula ostium is near the superior cavoatrial junction. Another cannulation technique for VV-ECMO is femorofemoral approach with the drainage cannula inserted through a femoral vein up to the IVC and the return cannula inserted through the contralateral femoral vein up to the right atrium.[4] The common limitation of these cannulation techniques is if there is any obstruction in the IVC, the cannula in the IVC will be prevented from accessing the optimal location at the inferior cavoatrial junction.

Based on an original design of Wang and Zwischenberger, Avalon Laboratories (Rancho Dominguez, California, USA) developed a dual lumen cannula which allowed VV-ECMO system to be established with a single-site venous cannulation,[5] Avalon Elite Bicaval Dual Lumen Cannula (hereafter referred to as 'Avalon cannula') is made primarily of polyurethane copolymer reinforced with small stainless steel wire coil, and divided internally by a deflectable but non-distensible membrane into two separated channels: one channel draining deoxygenated blood from distal and proximal ports, and the second channel allowing oxygenated blood to return to the right atrium via the middle port,[6] Avalon cannula can be inserted percutaneously via the right IJV and advanced through the superior vena cava (SVC) to the IVC. Dual lumen cannula requires precise placement of its distal tip in the IVC and its middle port at the level of the right atrium, usually accomplished under fluoroscopy or transoesophageal echocardiography (TOE) guidance,[7] However, in COVID-19 scenario, fluoroscopy is not always feasible, and TOE should be avoided because of high risk of aerosol generation, despite endotracheal intubation. We report a case of dual lumen cannula placement for VV-ECMO in a patient with COVID-19 infection under transthoracic echocardiography (TTE) guidance and propose a protocol to avoid potential complications of this technique.

CASE PRESENTATION

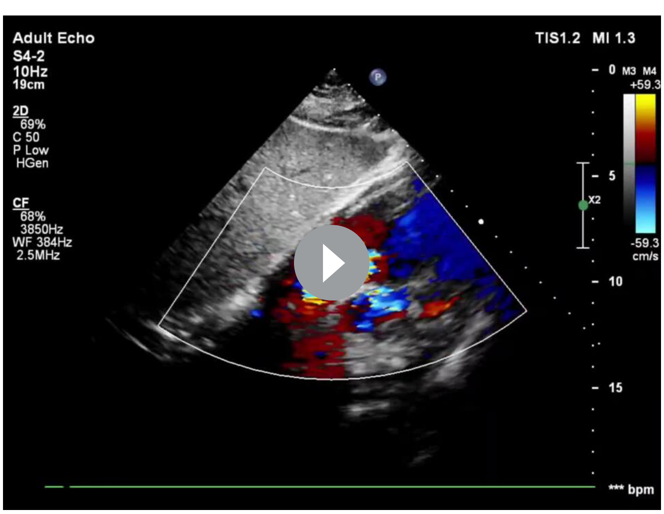
A woman in her 50s with a medical history of hypertension was admitted to the hospital because of fever and cough which had lasted for 1 week. She developed shortness of breath 2 days after admission and required supplementary oxygen therapy. Her respiratory failure deteriorated over the next 5 days and eventually necessitating endotracheal intubation and mechanical ventilation. A haemodialysis catheter was placed in the left femoral vein for planned cytokine adsorption filter. Following further respiratory failure despite best ventilation strategy, the patient was then transferred to our hospital, the region's ECMO centre.

INVESTIGATIONS

Nasopharyngeal swab test was positive for SARS-CoV-2 on reverse transcriptase PCR assays. Vascular ultrasound demonstrated deep vein thrombosis in the left lower limb with extension to the left common iliac vein and the lower portion of the IVC. Bedside echocardiography revealed increased pulmonary systolic blood pressure with estimated pulmonary artery systolic pressure of 45 mm Hg but no signs of right ventricular dilatation.

TREATMENT

The patient was started on therapeutic dose of unfractionated heparin. The haemodialysis catheter was withdrawn and an IVC filter was placed through the patent right femoral and iliac veins to prevent massive pulmonary embolism. Her respiratory failure further deteriorated within 24 hours of IVC filter insertion and decision was made to proceed to VV-ECMO. Since the IVC filter would impede the femoral cannula in traditional double



Video 5 After adequate rotational adjusment, the returning blood from the middle port was correctly oriented towards the tricuspid valve

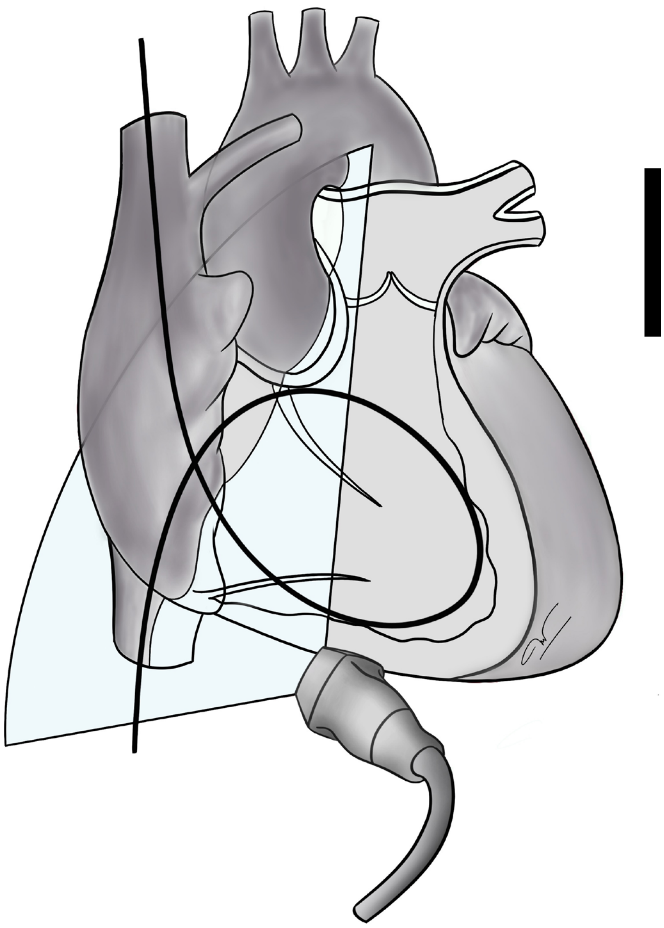


Figure 2 Schematic drawing illustrates how to visualise 'bending' phenomenon of the RV looping by rotating the transducer slightly in the clockwise direction in order to align the ultrasound beam with the distal portion of the guidewire (illutrastrated by Ngoc Minh Le). RV, right ventricular.

Table 1 Malposition complications and respective solutions in Avalon cannula placement

Complications	Troubleshooting
A. Guidewire dislocation	
Guidewire has not yet in the IVC	Guidewire can be in the RV or the coronary sinus. Withdraw the guidewire and try advancing it slowly several time. Exchange a harder guidewire if necessary.
Guidewire is dislocated from the IVC	Advancing deeply the guidewire into the distal part of the IVC up to the iliac vein. Hold the guidewire properly when exchanging dilators and advancing the cannula over-the-wire.
Guidewire looping despite its distal part remains in the IVC	Re-examining other echocardiographic views (parasternal RV inflow, subcostal four-chamber). Observing meticulously the entire pathway of the guidewire in bicaval subcostal view of TTE: make sure that **the cephalad portion of the guidewire is not near the aorta and not pass through the tricuspid valve.** Advancing the cannula cautiously over-the-wire. Paying attention to the ECG monitoring to early detect premature ventricular complexes, change the echo view to multiple planes (including subcostal four-chamber view, parasternal short axis view) whenever malposition is suspected.
B. Cannula dislocation	
Rotational dislocation	Fixed the cannula at the retromastoid region. Rotating the cannula to ensure the returning blood flow towards the tricuspid valve.
Longitudinal dislocation	Can be detected on radiography. Withdraw and fixation if dislocated deeply. Recannulation depends on the type of more difficult dislocation (into hepatic vein, into coronary sinus or coronary artery compression).

IVC, inferior vena cava; RV, right ventricular; TTE, transthoracic echocardiography.

cannula VV configurations, bicaval dual lumen cannula strategy was chosen.

Following uncomplicated right IJV puncture under ultrasound guidance, J-tip Radiofocus Guidewire M Standard 0.035" (Terumo Medical, Japan) was inserted with Seldinger technique from the right IJV through the SVC to the IVC. Distal tip of the guidewire was confirmed to be in the IVC by ultrasound with Philips S5-1 phased-array probe. After serial dilatations, the 27 Fr Avalon cannula (Avalon Laboratories, Rancho Dominguez, CA) was cautiously advanced along the guidewire with continuous guidewire visualisation in bicaval subcostal echocardiographic view (video 1). When the Avalon cannula was inserted deeply near the highest marker, the distal tip of the cannula was not seen yet on echo, but multiple premature ventricular complexes appeared on ECG monitor. Echocardiographic view was immediately changed to subcostal four-chamber view which revealed the Avalon cannula tip near the right ventricular apex (video 2), suggesting the guidewire must have formed an intraventricular loop causing subsequent malposition of the cannula. The cannula tip was immediately retracted into the SVC and the guidewire was withdrawn to unfasten the right ventricular loop and then slowly repositioned into the IVC under bicaval echocardiographic visualisation. The Avalon cannula was advanced into the IVC uneventfully thereafter.

Position of the Avalon cannula was re-examined following initiation of ECMO circuit by subcostal bicaval view. The Avalon cannula was displaced too deeply into the IVC, detected by the aliasing signals of the distal cannula tip and the middle port at infrahepatic portion of the IVC and lower portion of the right atrium, respectively (video 3). Subcostal four-chamber view also revealed returning jet emitted from the malposition middle port and flowing rightwards towards the anterior free wall of the right atrium (video 4), instead of leftwards anterolaterally towards the tricuspid valve. The Avalon cannula was withdrawn by 3 cm and rotated 90° anticlockwise to direct the returning jet into the tricuspid valve ostium (video 5). ECMO parameters were then optimised rapidly.

OUTCOME AND FOLLOW-UP

On the first day of VV-ECMO, haemodynamic and blood gas analysis parameters were stable. Unfortunately, on day 2 of VV-ECMO, the patient developed abdominal distension. Nasogastric tube suction revealed bright red blood and her haemodynamic deteriorated rapidly despite resuscitation effort and haemostatic therapies. Three days after ECMO application, she died from catastrophic gastrointestinal bleeding.

DISCUSSION

Apart from complications seen in traditional ECMO configurations, malposition is the notable complication when using Avalon cannula and can occur during Avalon cannula insertion or after the procedure.[8–10] During the procedure, advancing the cannula from the SVC passing through the right atrium down to the IVC is a key step which crucially requires correct prior placement of the guidewire. If the SVC and the IVC are not

Table 2 Protocol for Bicaval dual lumen Avalon cannula placement under transthoracic echocardiography guidance

Step	How to do
1	Place an X-ray cassette underneath the patient's back. Insert the guidewire through the IJV puncture until observing the guidewire in subcostal bicaval view.
2	Re-examine and exclude RV looping with subcostal bicaval view (guidewire bending towards the tricuspid or aortic valve), subcostal four-chamber view (guidewire in the RV inlet and RV sinus), subcostal short-axis view (guidewire in the right ventricular outflow tract), and if possible: parasternal RV inflow and other parasternal and apical views.
3	Estimate the distance from the IJV puncture to the xiphoid processus. After multiple dilatation, advance the Avalon cannula cautiously with continuous ECG monitoring and real-time subcostal bicaval view observation. When the cannula is about to attain the right atrium, exchange alternatively between the subcostal bicaval view and subcostal four-chamber view for early detection of malposition cannula into the RV. This step is successful when observing the distal part of the cannula in the IVC.
4	Initiate the ECMO circuit. Use the subcostal four-chamber view, modifying and focusing on the right atrium. Adjust colour gain and Nyquist limit to best obtain the jet emanating from the infusing port. Rotate the cannula to make the returning blood flow towards the tricuspid valve. Fix the cannula to avoid rotational dislocation.
5	Perform bedside chest radiograph (with the previously placed X-ray cassette) to make a standard landmark for cannulation.
6	Re-examine the cannula position by ultrasound and X-ray daily and whenever suspected any abnormality with ECMO circuit.

ECMO, extracorporeal membrane oxygenation; IJV, internal jugular vein; RV, right ventricular.

aligned, or there is a prominent Eustachian valve, the tip of the guidewire will be prevented from running into the IVC ostium and tend to migrate into the right ventricle. Furthermore, the guidewire can be bent and form a loop (usually through the tricuspid valve into the right ventricle) while its distal portion is still in the IVC, creating a false impression that the entire guidewire has been in its correct position and suitable for cannulation (figure 1 and video 1). Advancing the cannula over a looping wire can lead to displacement of the cannula into the right ventricle and cause right ventricular perforation.[11] Fluoroscopy is superior to both TOE and TTE in avoiding 'looping' phenomenon because of its ability to track the entire length of the wire and continuous real-time surveillance of the trajectory of the cannula. Despite being used commonly in Avalon cannula placement in non-COVID-19 patients, TOE sometimes cannot visualise the IVC appropriately due to the natural leftward curvature of the terminal oesophagus.[8 12] Compared with TOE, TTE offers better visualisation of the infradiaphragmatic guidewire in the IVC, although parasternal and apical views usually have poor acoustic windows.[13] Yastrebov *et al* suggested using a combination of TOE and TTE to compensate for the limitation of acoustic window of each modality and examining meticulously with numerous additional ultrasound views to avoid overlooking the abnormal trajectory of the guidewire[12] Even with this combination, it remains challenging to visualise three-dimensional non-planar looping phenomenon by two-dimensional echocardiographic planes. However, we notice that if guidewire looping occurs with its distal portion remains in the IVC, the guidewire portion just cephalad to the IVC ostium must be bent towards the tricuspid valve, either the inferior part of the tricuspid ostium or the superior part of the tricuspid ostium near the aortic valve, as illustrated in figure 1. This 'bending' phenomenon is easily overlooked during the procedure because the echocardiographer usually focuses on the IVC and rarely aware of the correlation between the higher part of the guidewire and surrounding cardiac structures. Slightly clockwise rotation of the ultrasound beam from standard bicaval view can help to visualise the 'bending' phenomenon better (figure 2).

Even following accurate cannulation, the cannula position should be checked immediately after fixation and during follow-up. A recent study demonstrated up to 38% of patients requiring echo-guided cannula adjustment after initial successful cannula positioning,[14] Avalon cannula dislocation can be classified into longitudinal and rotational. In case of longitudinal dislocation, the cannula tip may be advanced too deeply and cause hepatic congestion, either directly by cannula threading into the hepatic vein, or indirectly by retrograde flow emanating from the middle port.[13 15 16] On the contrary, the cannula tip may be too shallow in the right atrium and impacts the surrounding structures, such as right coronary artery compression, coronary sinus insertion or is deviated into the right ventricle and causes tricuspid injuries and even right ventricular perforation.[8 11 17] Rotational dislocation occurs when the middle port is not oriented towards the tricuspid valve, leading to the returning oxygenated blood impinging the right atrial wall rather than flowing towards the right ventricular inlet. This dislocation is unique to the Avalon cannula and usually discovered by four chamber view of TOE due to its high-quality resolution,[10 18] but can be still detected by subcostal four chamber view, as described in our case. We have summarised possible complications and their respective solutions in table 1 and suggested a protocol to avoid complications related to cannula malposition in table 2.

Learning points

- Transthoracic echocardiography could be a feasible guidance method for bicaval dual lumen Avalon cannula placement for venovenous extracorporeal membrane oxygenation in COVID-19 patients.
- To avoid the displacement of Avalon cannula into the right ventricle, meticulous observation should be made to discover the abnormal 'bending' of the intracardiac guidewire portion towards the tricuspid and aortic valve because it can indicate right ventricular looping, despite the presence of the distal guidewire in the inferior vena cava.
- A thorough protocol combining ultrasound techniques and intraprocedural ECG monitoring should be followed to avoid complications related to cannula malposition during and after the procedure.

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Case reports provide a valuable learning resource for the scientific community and can indicate areas of interest for future research. They should not be used in isolation to guide treatment choices or public health policy.

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