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Pediatric extracorporeal membrane oxygenation: Our experience with single-vessel cannulation

Pediatrik hastalarda ekstrakorporeal membran oksijenasyonu: Tek damar kanülasyonu deneyimimiz

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ABSTRACT

Background: In this study, we present our experience with bicaval, dual-lumen, venovenous extracorporeal membrane oxygenation in pediatric patients with severe respiratory failure.

Methods: Between September 2015 and May 2019, a total of nine pediatric patients (7 males, 2 females; median age 3.1 years; range, 0.3 to 7.4 years) hospitalized in the pediatric intensive care unit due to severe respiratory failure who were cannulated using a bicaval, dual-lumen, venovenous catheter were retrospectively analyzed. Patient demographics, cannulation details, complication of catheter use, and outcomes were recorded.

Results: The median duration of extracorporeal membrane oxygenation support was nine (range, 2 to 32) days. One patient required conversion to venoarterial extracorporeal membrane oxygenation and one patient required conversion to conventional double-cannulated venovenous extracorporeal membrane oxygenation. Of the patients, 33% suffered from bleeding complications. There were no cannula- or circuit-related complications. Adequate oxygenation and flow were obtained in all patients, except one. No mortalities were directly associated with the cannulation strategy used.

Conclusion: The bicaval, dual-lumen cannula can be safely used in pediatric patients with minimal complication rates and is our preferred method for venovenous extracorporeal membrane oxygenation support.

Keywords: Extracorporeal membrane oxygenation, intensive care, respiratory insufficiency.

ÖZ

Amaç: Bu çalışmada şiddetli solunum yetmezliği olan çocuklarda bikaval, çift lümen, venovenöz ekstrakorporeal membran oksijenasyonuna ilişkin deneyimimiz sunuldu.

Çalışma planı: Eylül 2015 - Mayıs 2019 tarihleri arasında şiddetli solunum yetmezliği nedeniyle pediatrik yoğun bakım ünitesinde yatmakta olan ve bikaval, çift lümen, venovenöz kateter ile kanüle edilen toplam dokuz pediatrik hasta (7 erkek, 2 kız; medyan yaş: 3.1 yıl; dağılım, 0.3-7.4 yıl) retrospektif olarak incelendi. Hastaların demografik özellikleri, kanülasyon detayları, kateter kullanım komplikasyonları ve sonuçları kaydedildi.

Bulgular: Medyan ekstrakorporeal membran oksijenasyon desteği süresi dokuz (dağılım, 2-32) gün idi. Bir hastada venoarteriyel ekstrakorporeal membran oksijenasyonuna geçiş, bir hastada ise konvansiyonel çift kanüllü venovenöz ekstrakorporeal membran oksijenasyonuna geçiş gerekti. Hastaların %33'ünde kanama komplikasyonu gelişti. Kanül veya devre ile ilişkili komplikasyon gözlenmedi. Biri hariç, tüm hastalarda yeterli oksijenasyon ve akıma ulaşıldı. Kullanılan kanülasyon tekniği ile doğrudan ilişkili mortalite görülmedi.

Sonuç: Bikaval, çift lümen kanül, pediatrik hastalarda minimum komplikasyon oranları ile güvenle kullanılabilir ve venovenöz ekstrakorporeal membran oksijenasyon desteği olarak bizim tercih ettiğimiz bir yöntemdir.

Anahtar sözcükler: Ekstrakorporeal membran oksijenasyonu, yoğun bakım, solunum yetmezliği.

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Extracorporeal membrane oxygenation (ECMO) support, which is used as a life-saving treatment in patients with cardiopulmonary insufficiency, was first performed in the pediatric population in the 1970s.[1] Initially, ECMO cannulation was performed with the venoarterial approach, which has since been shown to have high neurological complication rates due to internal carotid artery ligation.[2] The use of venovenous ECMO (VV-ECMO) in pediatric patients with respiratory failure, which has a lower rate of neurological, distal limb and thromboembolic complications and provides better cardiac and pulmonary oxygenation than venoarterial ECMO (VA-ECMO), began to spread in the early 1990s.[3,4]

Historically, VV-ECMO has required dual cannulation.[5] Recently, a bicaval, dual-lumen catheter has been developed which receives deoxygenated blood from both the inferior and superior vena cava and infuses oxygenated blood to the right ventricle. Bicaval, dual-lumen catheters which were initially used in the adult population and were shown to have lower complication rates with easier application, were later used in neonates.[6-8] In recent years, the use of these catheters in neonates and the pediatric population has been increasing with recent estimates showing that these patients account for 20.2% of cases.[9] A study examining the use of these catheters in the pediatric population was first published in 2013 and reported that the use of bicaval, dual-lumen catheters in pediatric VV-ECMO resulted in successful outcomes and was safer.[10]

In the pediatric population, the insertion of these catheters with single-vessel cannulation is the primary reason that problems are less frequent, as the small size of the femoral veins in neonates and infants cause significant problems. Other advantages are easier insertion, lower infection rates, and easier mobilization of patients.[6,8,10] In the field of pediatrics, data about the use and results of true percutaneous echocardiography- guided bicaval, dual-lumen ECMO cannulation performed at the bedside by intensive care specialists are quite limited, particularly in newborns and infants.[11]

In the present study, we present our experience with bedside percutaneous VV-ECMO application using the bicaval, dual-lumen Avalon cannula in pediatric patients with respiratory failure.

PATIENTS AND METHODS

Between September 2015 and May 2019, a total of nine consecutive pediatric patients (7 males, 2 females; median age 3.1 years; range, 0.3 to 7.4 years) hospitalized in the pediatric intensive care unit (PICU) due to severe respiratory failure who were placed on VV-ECMO support using a bicaval, dual-lumen, venovenous catheter were retrospectively analyzed. All cannulations were performed through the right internal jugular vein using the Avalon elite bicaval, dual-lumen cannula (Avalon Laboratories, LLC, CA, USA). Data were collected from our ECMO database and the medical records of the patients.

For each ECMO run, the following data were collected: patient's demographics (age, weight), diagnosis, comorbidities, pre-ECMO blood gas analysis, ECMO pump flow (mL/kg/min), cannula size, duration of ECMO support, clinical complications, and survival to-discharge. A written informed consent was obtained from each parent. The study protocol was approved by institutional Ethics Committee (2019/0266). The study was conducted in accordance the principles of the Declaration of Helsinki.

Catheter design

The Avalon bicaval, dual-lumen cannula has three ports: proximal, middle, and distal (Figure 1). Deoxygenated blood is removed from the superior vena cava/right atrium via the proximal port, while the distal port removes blood from the inferior vena cava (IVC). Once oxygenated in the ECMO circuit, blood is infused through the middle port and directed toward the tricuspid valve into the right ventricle. Another important aspect of the catheter design is the presence of wire-reinforcement in the cannula to prevent bending and mechanical flow obstruction after catheter insertion. The catheter sizes used in our study ranged from 13F to 19F.

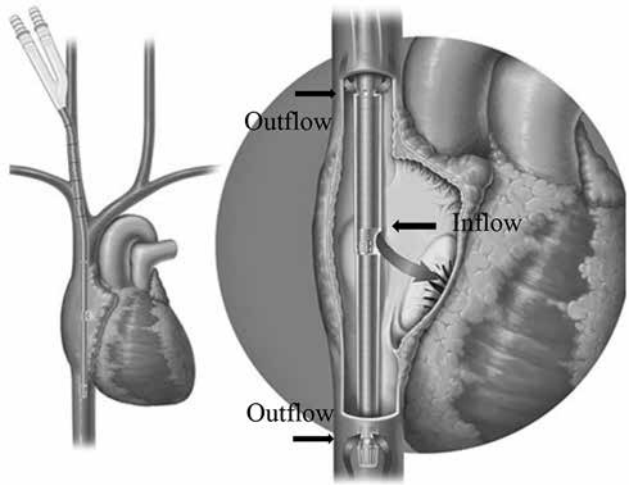

Figure 1. Schematic drawing of the Avalon catheter and correct positioning.

ECMO cannulation technique

The criteria for ECMO initiation consisted of one or more of the following: persistent acidosis, hypoxia, hypercarbia and hemodynamic instability in the setting of an underlying reversible pathologic disease process.

Nine patients were cannulated for VV-ECMO using the bicaval, dual-lumen cannula. Seven catheters were placed percutaneously, while two were placed via open cannulation procedures. The open technique was reserved for younger patients (less than six months) or those with lower body weight (less than 6 kg). Prior to cannula placement, the target distance from skin to cannula tip was measured on a chest radiograph, from the anticipated insertion site in the neck to the level of the suprahepatic IVC and right atrial junction (Figure 2). Prior to placement, a portable echocardiography device (Philips EPIQ 7, Philips Medical Systems, Bothell, WA, USA) was used to measure the diameter of the internal jugular vein to assist with appropriate cannula sizing. Cannulas were selected by comparing the patient's body weight and internal jugular vein diameter to the manufacturer-supplied pressure versus flow curves for the cannula. For percutaneous placement, all cannulas were placed using a standard Seldinger technique with serial dilations to enlarge the subcutaneous tract. In two patients in whom the Seldinger technique failed, cannulation was performed via the cut-down technique. After implantation, correct placement of the cannula was confirmed using transthoracic echocardiography and also portable radiological confirmation, if necessary.

When a patient required conversion from VV-ECMO to VA-ECMO, the carotid artery was isolated in the standard fashion using a cut-down technique. In one patient who needed a second venous cannula for advanced flow dynamics, the additional cannula was placed using the Seldinger technique. In both cases, the Y-connector was placed between the two catheter limbs of the Avalon cannula and connected to the venous return side in the ECMO circuit. This allowed the bicaval, dual-lumen cannula to be converted into a venous drainage catheter, thereby, preventing the possibility of requiring replacement with a standard single-lumen cannula.

ECMO Equipment and Post-Cannulation ECMO Management

The patients were placed on ECMO machines using a Maquet Bioline-coated circuit, which has a combined albumin/heparin matrix. The oxygenator was the Maquet Quadrox ID Bioline-coated oxygenator, which is made of polymethylpentene and works by gradient diffusion to remove carbon dioxide and deliver oxygen. The manufacturing company specifies gas transfer rates of up to 180 mL/min for

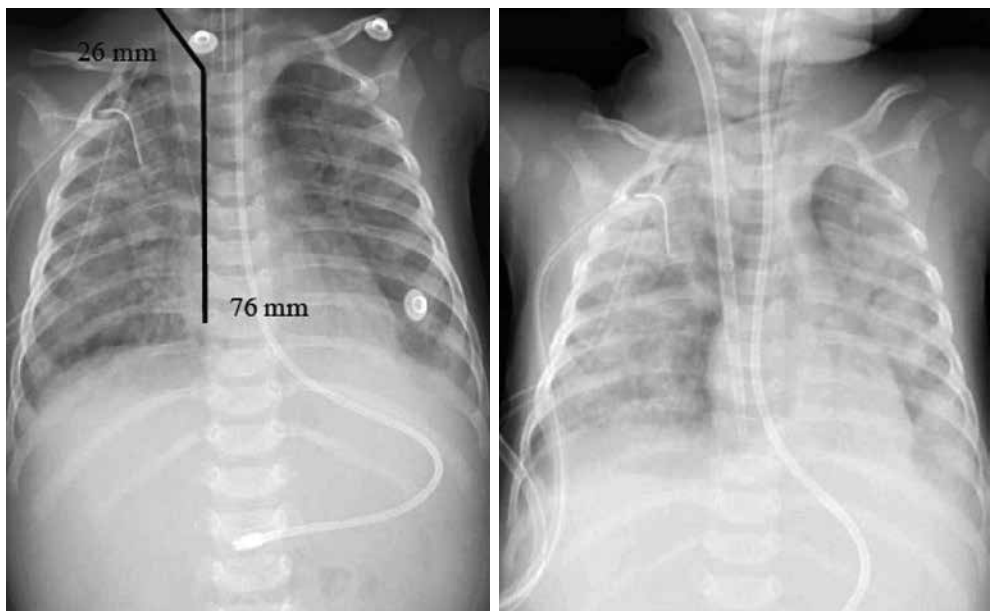

Figure 2. Pre- and post-cannulation chest radiograph with 13F Avalon cannula. The chest radiograph on the left demonstrates a pre-cannulation measurement of catheter length from the approximate level of insertion to the atriocaval junction. The right chest radiograph shows the cannula *in situ* at a depth of 10.2 cm.

oxygen and 140 mmHg/min for carbon dioxide. The circuit flow pump was a Maquet Rota-flow pump (Maquet Cardiovascular, Wayne, NJ, USA).

Once ECMO was initiated, the anticoagulation protocol was driven by the titration of heparin based on coagulation panels drawn every six hours. Heparin (10 U/kg) was administered before the cannula insertion, and an activated clotting time of 180 to 220 sec was maintained for the duration of ECMO support in the absence of bleeding. In case of bleeding (i.e., ECMO or central venous catheter site, hematuria, pulmonary hemorrhage, mucosal bleeding, or gastrointestinal bleeding), heparin infusion was interrupted and appropriate interventions with thrombocyte suspension, fresh frozen plasma, and fibrinogen/cryoprecipitate replacement were performed. After regression of bleeding, the anticoagulation protocol was continued.

The platelet count was measured separately, but concurrently. The target platelet count was kept higher than 100×10^3/UL and fibrinogen concentration was kept higher than 150 mg/dL. Functional antithrombin levels were maintained at levels higher than 80%. Ventilation management was based upon a lung-protective strategy to obtain desired tidal volumes of 3 to 5 mL/kg, while maintaining lung recruitment with additional positive end-expiratory pressure to keep oxygen saturation level above 82%. Paralytic medications were only used during cannula insertion or manipulation, or when oxygenation was inadequate despite maximum support on ECMO. Combinations of fentanyl and midazolam were used for sedation.

Decrease in partial pressure of carbon dioxide ($PaCO_2$), increase in partial pressure of oxygen (PaO_2), and increase in pulmonary compliance without any alterations in ventilator settings or extracorporeal flow and improvements in the posteroanterior X-ray graphs were defined as the signs of pulmonary improvement. In these patients, the ECMO weaning process was initiated by gradual reduction of oxygen support and increased ventilator support. Sweep gas flow was weaned, while PCO_2 levels were kept within the normal range. In patients with low oxygen support, low sweep gas flow, and acceptable values for ventilator settings and blood gases (PaO_2: 60-80 mmHg, PCO_2: 40-60 mmHg), separation was attempted by terminating sweep gas flow while continuing circulation and anticoagulation support. During these attempts, the patients' respiratory rate, heart rate, blood pressure, blood gases, oxygen saturation (SaO_2), capnography values, and agitation levels were closely monitored. In patients who demonstrated low airway pressures and sufficient values for blood gases, decannulation was performed.

Statistical analysis

Statistical analysis was performed using the Microsoft Office Excel 2016 (Microsoft Corp., Redmond, WA, USA) and IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in median (min-max) or number and frequency.

RESULTS

Throughout the study, 10 PICU patients were placed on ECMO. However, nine of these patients were

Table 1. Demographic and clinical characteristics of patients

Patient	Age (year)	Weight (kg)	Indication for ECMO	Associated comorbidities	No of hospital days prior to ECMO	Other organ failure
1	4	20	Mediastinal mass	T- cell lymphoma	4	None
2	6	22	Mycoplasma pneumonia	Trisomy 21	8	None
3	0.3	5	Metapneumavirus pneumonia	None	8	None
4	1.2	9	H1N1 influenza pneumonia	None	3	None
5	0.8	10	RSV pneumonia	None	7	Sepsis
6	0.5	5	Parainfluenza pneumonia	Prematurity (32 wk)	4	Sepsis
7	3.1	20	Activated charcoal aspiration	None	3	None
8	7.4	28	Fungal pneumonia	Burkitt lymphoma	3	Sepsis
9	4.9	17	Bacterial pneumonia	Brain tumor	6	Acute renal failure

ECMO: Extracorporeal membrane oxygenation; RSV: Respiratory syncytial virus.

Table 2. Pre-ECMO variables and ECMO physiology

Patient	pH*	PO_2 (mmHg)*	PCO_2 (mmHg)*	Flow rate at 24 Hr (mL/kg/min)	Vasopressors at cannulation	Duration of vasopressor support (day)
1	7.26	45	61	90	Epinephrine	2
2	7.25	52	63	84	None	NA
3	7.28	54	72	120	None	NA
4	7.25	42	60	96	None	NA
5	7.18	34	84	114	Epinephrine, norepinephrine	5
6	7.27	48	59	110	None	NA
7	7.29	52	57	86	None	NA
8	7.30	45	58	36	None	NA
9	7.28	41	38	78	Epinephrine, norepinephrine	2

ECMO: Extracorporeal membrane oxygenation; NA: Not applicable; * Pre-ECMO.

recipients of a dual-lumen VV-ECMO Avalon cannula and included in our study. The causes of respiratory failure necessitating ECMO support were as follows: mediastinal mass secondary to T-cell lymphoma (n=1), viral pneumonia (n=4), mycoplasma pneumonia (n=1), fungal pneumonia (n=1), bacterial pneumonia (n=1), and activated charcoal aspiration (n=1). The VV-ECMO patients' demographics, diagnoses, and clinical data are presented in Table 1.

The median weight at the time of venovenous cannulation was 10 (range, 5 to 28) kg. All VV-ECMO patients were acidotic prior to ECMO cannulation with a median pH of 7.27 (range, 7.18 to 7.30), a median $PaCO_2$ of 60 (range, 38 to 84) mmHg, and a median PaO_2 of 45 (range, 41 to 54) mmHg (Table 2). The ECMO flow rates in each patient, for the first seven days of cannulation, are presented in Figure 3. The median duration of ECMO support was

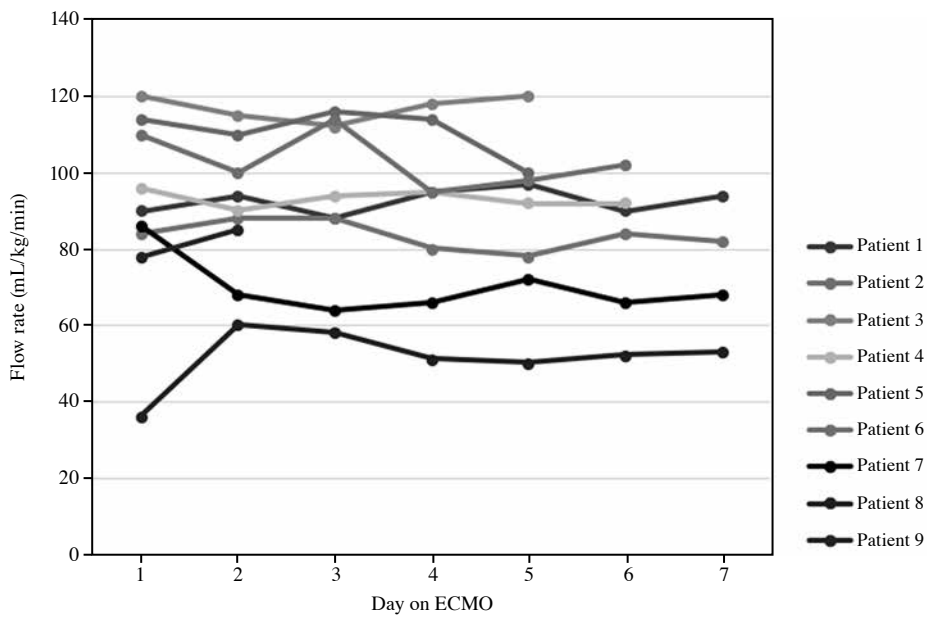

Figure 3. ECMO flow rates (mL/kg/min) in each patient for the first seven days of cannulation.
ECMO: Extracorporeal membrane oxygenation.

Table 3. ECMO outcomes

Patient	Duration of ECMO (day)*	Method of insertion	Access	Cannula size	Conversion to VA-ECMO & double VV-ECMO cannulation	Circuit exchange
1	9	Seldinger	IJ	19F	No	No
2	12	Seldinger	IJ	19F	No	No
3	5	Seldinger	IJ	13F	No	No
4	14	Cutdown	IJ	16F	No	No
5	5	Seldinger	IJ	16F	No	No
6	6	Cutdown	IJ	13F	No	No
7	18	Seldinger	IJ	19F	No	Yes
8	32	Seldinger	IJ	19F	Double VV-ECMO cannulation	Yes
9	2	Seldinger	IJ	19F	VA-ECMO	No

ECMO: Extracorporeal membrane oxygenation; * Including venoarterial or dual-lumen run if conversion required; VA: Venoarterial; VV: Venovenous; IJ: Internal jugular.

nine (range, 2 to 32) days. Two patients required circuit exchange, and the median time to first exchange was 16.5 (range, 15 to 18) days (Table 3). All circuit changes were related to clot formation; in two of the patients, the circuits were able to be exchanged without any complications.

One patient required conversion from VV-ECMO to VA-ECMO within two days after the ECMO support was initiated due to severe cardiac dysfunction. There was no complication caused by the conversion from VV to VA-ECMO. One patient required insertion of an additional venous cannula to improve flow dynamics. A 21F venous cannula was inserted into the femoral vein to ensure adequate flow rate. The dual-lumen cannula in the internal jugular vein was converted to the return line via the Y-connector tubing (Table 3).

Four of the nine patients (44%) survived until hospital discharge, while five patients (56%) died. The cause of deaths included brain herniation due to intraventricular hemorrhage (n=1) and multiple organ failure (n=4) (Table 4).

In terms of anticoagulation-related major complications, one patient developed intraventricular hemorrhage as evidenced by transcranial ultrasonography with transtentorial herniation on the fifth day of cannulation and was declared brain dead. Subdural hemorrhage, which developed in one patient, was managed by erythrocyte transfusion and correction of coagulopathy. Cranial imaging of all surviving cases was performed to detect major anticoagulation-related complications. One patient underwent plasmapheresis due to coagulopathy (Table 4).

Table 4. ECMO-related complications and survival

Patient	Bleeding complications	Mechanical complications	Survival	Cause of death
1	None	None	Alive	
2	None	None	Alive	
3	Intraventricular hemorrhage	None	Dead	Brain herniation
4	Subdural hemorrhage	None	Alive	
5	None	None	Dead	Multiple organ failure
6	None	None	Dead	Multiple organ failure
7	None	None	Alive	
8	DIC	None	Dead	Multiple organ failure
9	None	None	Dead	Multiple organ failure

ECMO: Extracorporeal membrane oxygenation; DIC: Disseminated intravascular coagulation.

None of the patients experienced major catheter-related complications, including cardiac perforation, major vessel injury, or recirculation complications. Only one patient required repositioning of the cannula. Displacement was confirmed with a chest radiograph taken in the intensive care unit. The cannula needed 2-cm of retraction, as it gradually migrated distally after 10 days of use. The cannula was positioned under ultrasonic guidance without any difficulties.

DISCUSSION

Over the past three decades, ECMO has been widely used in the treatment of potentially reversible causes of cardiopulmonary failure refractory to medical management.[1] Following the earliest report of VV-ECMO in three newborns with hypoxemic respiratory failure,[12] the use of VV-ECMO has increased worldwide in newborns, older children, and adults with respiratory failure for a multitude of reasons.[3,13] The most recent report in 2012 by Skinner et al.[14] has validated the effectiveness of VV-ECMO even with risk adjustments for age, advanced respiratory support, and the use of vasopressor agents.

Historically, VV-ECMO has often required the use of two cannulas: one for venous drainage and the second for venous return. However, the advent of the dual-lumen ECMO cannula has obviated the need for two access sites. Although dual-lumen cannulas have found limited use due to problems associated with lumen size, frequent recirculation and mechanical catheter obstruction, the Avalon bicaval, dual-lumen cannula was reportedly designed to address each of these issues. Since its introduction, the cannula has been employed for VV-ECMO via percutaneous or open techniques. Bermudez et al.[6] described their initial experience in 11 adult patients where the cannula was able to provide adequate oxygenation during ECMO support without any catheter-related complications or deaths. Javidfar et al.[15] also described the successful use of the bicaval, dual-lumen catheter in 27 adults with an overall survival of 56% and one occurrence of superior vena cava injury. Lazar et al.[8] published an article on the use of dual-lumen cannulas in the neonatal population and they reported no cannula-related vascular or cardiac complications. The first institutional report on the Avalon bicaval, dual-lumen cannula in the pediatric population was published in 2013 by Fallon et al.[10] They reported that the catheter could be placed safely and had an acceptable complication profile. Similar to these studies, we used Avalon catheters in nine pediatric patients receiving VV-ECMO and all patients, except one, were found to have adequate oxygenation and flow rate. None of the patients had catheter-related complications. The reason for inadequate flow rate and oxygenation in one patient was associated with the use of a smaller than required cannula size.

As with any new device, refinements in placement technique and use of image guidance have allowed for improved safety in the use of this device. We would agree with the previous studies and the manufacturer's recommendation that the use of image guidance should be employed for safe placement of these cannulas.[10,16,17] One of the modifications in our placement technique is the measurement of the internal jugular vein diameter using bedside ultrasound before placement. This measurement allows the intensive care specialist to accurately estimate optimal cannula size, thereby preventing any injury that may be caused by placing a cannula too large for the internal jugular vein. Furthermore, using a preplacement chest radiograph, the depth of insertion can be determined preoperatively based on the distance from the anticipated insertion site on the neck-down to the level of the suprahepatic IVC/right atrium junction. A final safety measure is the use of real-time echocardiography during cannula placement to confirm that the catheter has been placed at the correct depth, to ensure that the oxygenated infusion port is pointed toward the tricuspid valve, to evaluate the initial ECMO flow, and to observe that no vascular injury has occurred. We used chest radiography to identify the depth of cannula placement in all patients. Also, the cannula position was confirmed by real-time echocardiography in all patients. Chest radiography and echocardiography were also used for the detection of cannula displacement. Displacement should be suspected in the presence of acute oxygen desaturation while on support, and changes notable at the cannula level with signs of steal of oxygenated blood recirculation in the inflow side of the cannula. In our pediatric series, only one patient required repositioning of the cannula. Displacement was confirmed with a chest radiograph taken in the intensive care unit. We repositioned the cannula under ultrasound guidance without any difficulties.

In the present study, the rate of adverse outcomes is similar to a recent longitudinal report of pediatric ECMO patients with data from the Extracorporeal Life Support Organization (ELSO) Registry.[18] Mortality in this series of over 3,000 patients ranged from 39 to 50% and was found to be dependent on the patient age. The study reported that mortality rates were higher in the recipients of VA-ECMO (49% vs. 30%), and that mortality after conversion from VV to VA-ECMO was similar to the VA group (51%). In the adult age group, mortality rates of 45% and 44% in

VV-ECMO series performed with dual-lumen cannula were reported.[6,15] In the study by Fallon et al.,[10] a mortality rate of 55% was reported in a pediatric group of patients who underwent venovenous ECMO with the Avalon dual-lumen cannula, which is relatively high. Although the mortality rate in our study is slightly higher than that of studies including adult patients, this is most likely associated with our small sample size, making the comparison of the results difficult. Other concerns with this cannula have stemmed from the occurrence of major vascular injuries during placement or after placement, mainly in neonates and small infants. A recent article by Lazar et al.[8] on the use of this cannula in a neonatal population did not report any cannula-related vascular or cardiac complications. Although we had no catheter-related complications or major vessel injury, serious events including right ventricular rupture with tamponade have been previously reported with Avalon catheters.[19] As these complications are rare, our small sample size is inadequate to detect the true rate of these potentially fatal outcomes and a further, large-scale, multi-center studies or studies using a national/international ECMO database may be the only avenue by which the rates of such complications and their relationship with the Avalon catheter can be assessed.

Conversion to VA-ECMO may be required in cases with inadequate oxygenation and cardiac dysfunction, while receiving VV-ECMO. In our pediatric case series, conversion was required in two patients (22%). One patient underwent VA-ECMO conversion due to severe cardiac dysfunction. In one patient, due to inadequate flow rate and oxygenation, double VV-ECMO cannulation was switched and VA-ECMO was not required. Our conversion rate is consistent with the reported VV-ECMO to VA-ECMO conversion rates in the literature.[10,20] This specific cannula design allows for conversion to VA-ECMO and double VV-ECMO cannulation without the need for replacement of the cannula. One important consideration for conversion is that the arterial limb of the cannula must have the Y-connector placed to allow for flow within that lumen. This prevents stasis and clot formation within the limb. This technique was described with success in the adult population, where the Avalon cannula was attached to a Y-connector and used as a venous drainage system in patients with cardiopulmonary bypass and recipients of VA-ECMO through the axillary artery.[21]

In our study, we inserted the catheters percutaneously using the classical Seldinger technique in seven patients, and the procedure failed in only two patients and catheter insertion was successfully done via the cut-down technique in these patients. We also used an open cannulation technique in two patients which were under six months old or weighed less than 6 kg. Open cannulation techniques were used in the VV-ECMO cannulation performed by Avalon bicaval, dual-lumen cannula in the study conducted by Lazar et al.[8] In the pediatric case series of Fallon et al.,[10] they also used open technical procedures in children under 5 kg or under one years of age. In the aforementioned study, the percutaneous method was utilized for cannulation in all pediatric patients over 5 kg. The most recent analysis of the ELSO registry reported only 188 percutaneous cannulations in those aged under one year versus 1,117 surgical cut-downs, with no mention of neonatal cases.[11] In a study by Moscatelli et al.,[22] bedside percutaneous cannulation was successfully performed by the intensive care specialists in a series of 32 cases, most of whom were newborns, infants, or patients weighing less than 5 kg. Ellis et al.[23] also reported that percutaneous application of Avalon cannulas yielded significant technical success among 20 patients (<20 kg) who received VV-ECMO. In addition, successful percutaneous application of cannulas for VV-ECMO has been described in adult patients. In a study, of 33 patients who received VV-ECMO, there were 32 successful percutaneous applications.[24] Similarly, in these studies, the placement of the Avalon bicaval, dual-lumen catheter was reportedly easy and safe, similar to our experience.

The study has several limitations since it is retrospective and observational on a limited number of patients. Definitive conclusions cannot be drawn given the relatively small sample size, a common weakness of pediatric ECMO studies; similar numbers of patients are described in the available published reports on this topic.

In conclusion, our study results show that bicaval, dual-lumen extracorporeal membrane oxygenation cannulation performed at the bedside by intensive care specialists under echocardiography guidance can be feasible and safe for the pediatric population. We believe that, in experienced hands, echocardiography-guided percutaneous bicaval, dual-lumen cannulation in pediatric patients -similar to its use in the adult population- may be a valid alternative to the surgical cut-down technique.

Declaration of conflicting interests

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