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Avalon catheters in pediatric patients requiring ECMO: Placement and migration problems

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ABSTRACT

Purpose: The Avalon dual-lumen venovenous catheter has several advantages, but placement techniques and management have not been adequately addressed in the pediatric population. We assessed our institutional outcomes and complications using the Avalon catheter in children.

Methods: We reviewed all pediatric patients who had Avalon catheters placed for respiratory failure at our institution, excluding congenital heart disease patients, from April 2009 to March 2016. All patients were managed using our standard ECMO protocol, and cannula position was followed by daily chest x-ray and intermittent echocardiography (ECHO). Data included demographics, diagnosis, PRISM3 predicted mortality, ECMO duration, complications, and survival. The primary outcome was the need for catheter repositioning.

Results: Twenty-five patients were included, with mean age 8.3 ± 6.9 years and 15 ± 22 days of ECMO support. Overall survival was 68% (17/25). Fourteen patients (56%) underwent placement with fluoroscopy in addition to ultrasound and ECHO, primarily after 2013. Overall, thirteen patients (52%) had problems with cannula malposition. 9 of these (69%) required cannula repositioning. Three of 14 (21%) cannulas placed with fluoroscopy required repositioning, compared to 7/11 (64%) placed without fluoroscopy ($p = 0.05$).

Conclusions: Complications are common with the Avalon catheter in children. Safe percutaneous access requires ultrasound guidance, and use of intraoperative fluoroscopy in addition to echocardiography decreases malposition rates.

Level of evidence: IV (Prognosis study).

Strategies and cannulas used for extracorporeal membrane oxygenation (ECMO) have evolved since it was first used in a neonate in 1975 [1]. As ECMO evolved, the use of a venovenous (VV) configuration for treatment of respiratory failure has increased in popularity. Initially, VV-ECMO required a two-cannula technique with an internal jugular (IJ) infusion catheter positioned with its tip in the right atrium and a femoral drainage catheter positioned in the inferior vena cava (IVC). This strategy has a number of limitations, particularly in small children, including an increased level of invasiveness and increased procedural time (two cannulas inserted), recirculation [2], increased line infection and sepsis rates [3], and most importantly, the limited ability of the pediatric femoral vein to accommodate an adequately sized drainage cannula.

In response to these limitations, a dual-lumen single cannula, with distal infusion side-holes and proximal drainage side-holes, was implemented as early as 1989, using a VV catheter by Kendall Healthcare Products [4]. These cannulas were inserted into the IJ using an open technique. Since the tip was positioned in the right atrium, safe insertion required only plain radiographs without routine use of fluoroscopy or echocardiographic guidance [5]. However, given the proximity of the infusion and drainage ports, recirculation often became a significant problem, especially when increased oxygen delivery was required. Specific limitations in the pediatric population also include potential collapse and cavitation with non-wire-reinforced cannulas.

The Avalon dual-lumen intracaval cannula was designed to address many of the limitations of the two-cannula technique and the Kendall Healthcare VV Catheter. With the catheter tip properly positioned in the IVC, separate circumferential drainage holes are situated in the superior vena cava (SVC) and IVC, while an infusion side-hole is positioned in the right atrium. This design serves to decrease recirculation while still allowing for single cannula use [6–8]. While originally designed for adults, smaller Avalon cannulas have been used in neonates and children [9,10]. However, recent reports indicate higher risk for complications in this population [8,10,11]. Other studies recommended use of imaging and echocardiography at the time of cannulation with decreased complications and good outcomes [7,12,13]. We therefore

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aimed to evaluate the outcomes and complications of using the Avalon cannula in children at our institution, and hypothesized that the combined use of echocardiography and fluoroscopy during placement would minimize complications.

1. Methods

We conducted a retrospective review of all pediatric patients who underwent Avalon catheter placement for VV-ECMO at our institution from April 2009 to September 2016. Patients with congenital heart disease were excluded. All patients were managed using our standard ECMO protocol and cannula position was followed by daily chest x-ray and intermittent echocardiography (ECHO). Prior to 2013, patients were cannulated primarily with the aid of chest radiography and/or ECHO only, whereas from 2013 onward patients were cannulated using fluoroscopy and ECHO. Practice also changed toward the end of the study as all patients were taken to the operating room for cannulation.

Data collected included demographics, diagnosis, PRISM3 predicted mortality, ECMO support duration, complications, problems with positioning, instances of cannula repositioning, and survival. The primary outcomes assessed were problems with positioning and the need for cannula repositioning. Outcomes were compared between cannulation methods (ECHO only versus ECHO + fluoroscopy). Statistical analysis was performed using SPSS v.22.0 (IBM Corp: Armonk, NY). Statistics were primarily descriptive; comparisons were made using t-test and Fisher's Exact Test, with $p < 0.05$ defining significance.

2. Results

Twenty-five patients were included in the study; demographics and outcomes are summarized in Table 1. All patients had respiratory failure; secondary diagnoses included sepsis (24%), ARDS (44%) and pneumonia (68%). All cannulas were inserted percutaneously using ultrasound guidance; 14 (56%) were inserted with fluoroscopic guidance as well. Prior to 2013, cannulation was primarily performed with ECHO guidance to guide catheter tip position; two patients underwent placement without real-time imaging, having only CXR confirmation of catheter position. After April 2013, owing to standardization of practice, 9/9 cannulations used fluoroscopy and 8/9 utilized both fluoroscopy and ECHO. There was one cannula related death owing to perforation during cannula placement. One patient had brief cardiac arrest during cannulation which resolved with resuscitation and initiation of ECLS without obvious sequelae.

Thirteen patients (52%) had problems with cannula malposition leading to inadequate flow, recirculation, and pericardial effusions; 9 (69%) of these 13 required cannula repositioning (Table 1). Patients who experienced problems with cannula position had smaller cannulas than those who had no such problems; these patients also appeared younger, though this did not reach statistical significance (Table 2). Three of 14 (21%) cannulas placed with fluoroscopy went on to require repositioning, compared to 7/11 (64%) placed without fluoroscopy ($p = 0.05$). The decrease in cannula repositioning after practice change is reflected in the U-chart of cannula repositioning per 100 days (Fig. 1). Among repositioning-related complications, one attempt at repositioning failed and necessitated conversion to VA, while another resulted in a bloody pericardial effusion with tamponade which was relieved with percutaneous drainage. Three cannulas lodged in the hepatic veins as determined by ECHO, which was not evident on the chest x-ray. Overall, 5 of 10 (50%) patients who required repositioning died, compared to only 3 of 15 (20%) who did not require repositioning ($p = 0.19$).

Table 1
Population demographics and outcomes.

Demographics	
Age @ Cannulation (years)	8.3 ± 6.9 (range 0.4–24.5)
Male gender	16 (64%)
Cannula size (French)	23.0 ± 5.6 (range 16–31)
Cannula size mode	19F (10/25; 40%)
ECMO Duration (days)	15 ± 22 (range 0–104)
PRISM III Predicated Mortality	30.8 ± 33.2 (range 0.3–95.9)
Fluoroscopy used for placement	14 (56%)
Outcomes	
Cannula malposition/flow problems	13 (52%)
Recirculation	2/13 (15%)
Lodged in Hepatic Veins	3/13 (23%)
Tip in Right Atrium	2/13 (15%)
Tip too deep in IVC	2/13 (15%)
Undetermined from records	4/13 (31%)
Cannula repositioned	10 (40%)
Mortality	8 (32%)
Mortality secondary to cannulation	1 (4%)

3. Discussion

Venovenous (VV) ECMO is an effective modality for management of respiratory failure in the pediatric population. The Avalon dual lumen cannula was designed to obviate previous problems with two cannula and single cannula techniques. Although the cannula was originally designed for adults, VV-ECMO using the Avalon cannula is feasible in children. However, it is fraught with many complications and requires additional imaging modalities for insertion, monitoring, and repositioning [8,9,14].

In our analysis of 25 patients who were placed on VV ECMO using the Avalon cannula, 52% experienced problems with cannula malposition leading to inadequate flow, recirculation, and pericardial effusions. These patients had significantly smaller cannulas, and tended to be younger. Of these patients, 69% required cannula repositioning. Although all cannulas were placed percutaneously using ultrasound, both fluoroscopy and echocardiography were not routinely used in our practice until 2013. Up until this time, cannulations were performed in the pediatric intensive care unit (PICU) without fluoroscopic capability, where 75% were done with echocardiographic guidance. This guidance was helpful, but was limited. Wire visualization with ECHO can only be obtained in one anatomic location at a time. This made ensuring proper location along the entire length of the wire very difficult and often made manipulating the wire into the IVC prohibitively challenging. However, toward the second half of the study time frame, we changed our practice to include routine use of both fluoroscopy and ECHO. Use of fluoroscopy did appear to decrease the need for cannula repositioning (21% vs. 64%; $p = 0.05$). We transported most patients to the OR to have fluoroscopic capability, but upon changing our standard of practice we also, through a number of institutional process changes, made fluoroscopy available in the PICU for those patients unable to be transported. This now allows for fluoroscopy use for all Avalon cannula placements.

Different strategies are utilized for placement of the Avalon cannula. Cannulation can occur in the ICU or operating room via an open or percutaneous approach, with use of various combinations of ultrasound, fluoroscopy, and echocardiography [12,13]. In adults at our institution, the Avalon cannula is placed percutaneously initially using ultrasound guidance, with advancement of a wire into the distal IVC or iliac vein under fluoroscopic guidance, and ultimate placement of the cannula

Table 2
Characteristics of patients who did and did not have positioning problems.

	Position Problems	No Position Problems	p-value
Fluoroscopy Used at Insertion	39%	75%	0.11
Age (years)	6.0 ± 7.1	10.8 ± 6.1	0.09
Cannula Size (French)	20.7 ± 5.2	25.7 ± 5.2	0.02
Duration of ECMO Support (days)	16.5 ± 13.2	13.5 ± 29.0	0.74

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