
VV ECMO cannulation in infants and children under 10 kg: Evolving strategies, outcomes, and innovations

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Abstract

Venovenous extracorporeal membrane oxygenation (VV ECMO) has become an increasingly preferred modality for respiratory support in neonates and infants under 10 kg, driven by a growing recognition of its neurological safety advantages over venoarterial (VA) ECMO. Historically, VV ECMO was limited in this population due to small vessel size, anatomical constraints, and technical challenges in achieving stable high-flow access. Recent advancements, including the development of the Crescent Right-Atrial (RA) dual-lumen cannula and increasing adoption of multisite cannulation strategies, have significantly expanded VV ECMO feasibility in neonates and small infants. Institutional experiences now support the safety and efficacy of VV ECMO in this vulnerable group when performed with skilled teams and advanced imaging guidance. This review synthesizes current evidence, highlights evolving cannulation techniques, and presents innovative solutions aimed at improving outcomes for infants and children under 10 kg requiring VV ECMO.

Keywords

VV ECMO, pediatric ECMO, cannulation strategies, dual-lumen cannula, neonatal intensive care, crescent RA, Avalon, multisite ECMO

Introduction

Extracorporeal membrane oxygenation (ECMO) has transformed care for pediatric patients facing severe cardiopulmonary failure. However, in neonates and small infants, ECMO cannulation remains especially challenging because of their small vessel size, rapidly evolving physiology, and heightened risk of complications.¹ Traditionally, VA ECMO was favored for infants as it provides both cardiac and respiratory support and is technically easier to establish via central arterial and venous access. Nevertheless, VA ECMO involves use of the carotid artery, which carries increased risks of neurologic injury and raises long-term concerns about cerebral perfusion.²⁻⁵

The growing preference for VV ECMO reflects efforts to avoid arterial cannulation and reduce neurological

morbidity, particularly when isolated respiratory support is present. However, anatomical constraints—especially small venous caliber and the difficulty of achieving stable, high-flow cannulation—have historically limited VV ECMO in children under 10 kg.^{6,7}

Recent advances in cannula technology, notably the Crescent Right Atrial DLC^{8,9} along with improved

comprehension of bicaval cannula positioning and flow dynamics¹⁰⁻¹⁴ and a better understanding of multisite cannulation techniques,¹⁵ are broadening VV ECMO applicability in neonates and small infants. This review summarizes contemporary VV ECMO cannulation approaches in children under 10 kg, emphasizing technical hurdles, clinical outcomes, and innovative solutions. By integrating key institutional experiences and emerging technologies, it aims to inform best practices in this rapidly evolving field.

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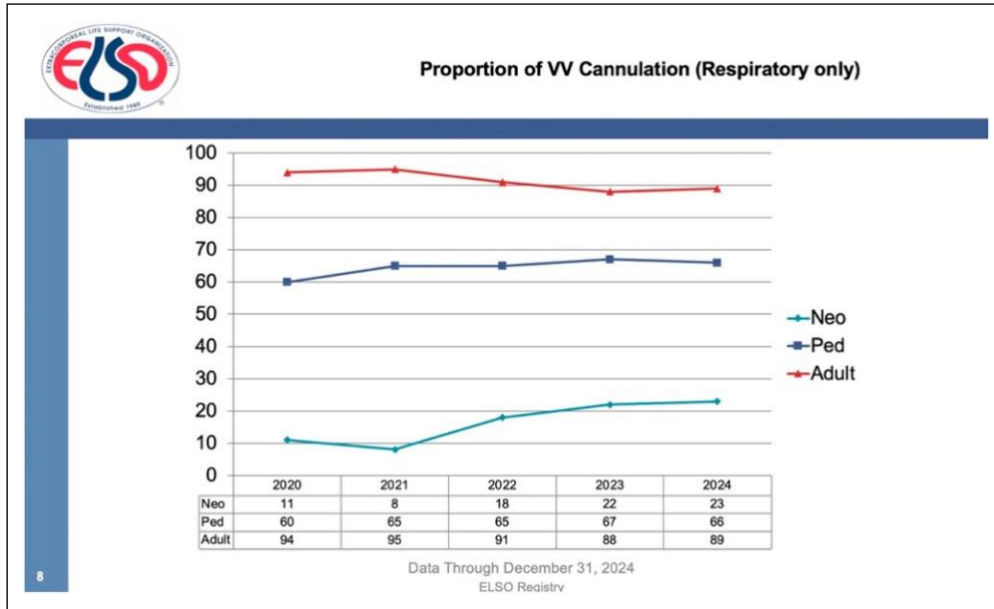


Figure 1. Extracorporeal life support organization. International trend report. April 2025.

Historical context and present practice

VV or VA ECMO? The real question

The question here is not whether VV or VA ECMO should be used in a child with respiratory failure. Rather, the core consideration is the optimal ECMO strategy to support infants and small children with respiratory failure, since older children are typically cannulated like adults using multisite VV ECMO.

In the early days of neonatal ECMO, VA support was the standard, pioneered by Bartlett et al. in the 1970s.¹⁶ At that time, limitations in venous access and cannula design made VV ECMO im-practical. Consequently, ECMO for respiratory failure in small children—those weighing less than 15 kg—was typically performed via VA access, using the right internal jugular vein for drainage and the common carotid artery for oxygenated blood infusion.

As awareness grew about the neurologic risks associated with carotid artery ligation, interest shifted toward single-site VV access.^{4,17} The introduction of the dual-lumen cannula (DLC) in 1989 facilitated wider adoption of VV ECMO in pediatric patients, especially since femoral vessels tend to be underdeveloped in children too young to walk.^{18,19}

Another approach, initially used in the 1990s²⁰ and recently revived, involves multisite VV cannulation—with a drainage cannula in the superior vena cava and a reinfusion cannula in the femoral vein.¹⁵ However,

this method remains limited to a few centers due to the small size of these veins in infants.

VV ECMO offers several safety advantages over VA ECMO, chiefly by avoiding carotid artery cannulation.^{3,4} Multiple studies have reported better survival rates with VV ECMO, noting that VA ECMO is a significant risk factor for neurological injury.^{3,4,7,21,22} Polito et al found that the odds ratio for neurologic complications was 1.6 (95% confidence interval) for VA ECMO, significantly higher than neonates supported with VV ECMO ($p < .001$).^{17,21} A recent report from the ELSO registry on 1686 patients <20 kg, comparing VV and VA ECMO for respiratory indications, found that VV ECMO was associated with significant higher survival even after removing confounding factors (79% v/s 71%; $p < .001$).²² Still, these findings are complicated by se-

lection bias, unmeasured clinical variables, and their retrospective nature; so whether VV ECMO is definitively less harmful in neonates remains debated.

Additionally, VV ECMO does not alter cardiac filling or increase afterload as VA ECMO does, and it eliminates the need for cardiac venting. Dual-lumen VV cannulation enables single-site venous access, facilitating patient mobilization and even allowing patients to remain awake. Other benefits include shorter cannulation times, avoidance of ischemic lung injury seen in VA ECMO, maintenance of pulsatile blood flow, and the theoretical advantage that emboli pass through the pulmonary circulation rather than directly into systemic circulation.²³ These points have been widely discussed over the past three decades.

Given these advantages, one might expect VV ECMO use to continue rising—but that has not been entirely the case.²⁴

Utilization trends: What the data show

According to the ELSO report published in April 2025,²⁴ in adults, the use of VV ECMO for respiratory support has become predominant, now accounting for approximately 90% of respiratory ECMO cases.

In pediatric patients, the use of VV ECMO has steadily increased and currently represents about 66% of respiratory ECMO cases (Figure 1).

In contrast, in neonates, the use of VV ECMO has remained largely unchanged, staying around 25% from 2018 to 2022²⁵ (Figure 2), with VA ECMO via carotid cannulation still frequently utilized despite its well-recognized higher neurological risks (Figure 3).

There was even a period where neonatal VV ECMO utilization dropped below 25%, possibly related to the shortage of the Origen cannula.^{26,27} Specifically, there was a noticeable decline in 2020–2021, with VV ECMO use decreasing to 11% in 2021. However, this pattern now appears to be shifting. From 2020 to 2024, the proportion of VV ECMO in neonates has nearly doubled, increasing from 11% in 2021 to 23% in 2024, returning to the levels observed in 2018, which was also 23%.^{24,25} This increase is likely influenced by recent advancements such as the Crescent RA cannula and the broader adoption of multisite VV cannulation strategies. It is also important to note that the use of the Avalon cannula likely remained stable during this time, as some centers have discontinued its use while others have optimized its deployment with ultrasound-guided in-sertion and surveillance protocols.^{11–14}

This raises an important question: why is VA ECMO still used so frequently despite its likely association with higher complication rates? Is this practice justified?

One key reason lies in the size and anatomical limitations of pediatric patients. Unlike in older children, where adult-type ECMO equipment and cannulation strategies can be applied, these options are not feasible in neonates and small infants. Given that the femoral vessels in non-ambulatory children are typically too small, VV ECMO for respiratory support is usually achieved with single-site VV cannulation using a DLC, thereby sparing the carotid artery. However, limitations in cannula availability, cost and size remain critical barriers. Historically, the Avalon bicaval cannula and the Origen RA cannula were the primary options, but following the withdrawal of the Origen cannula, many centers reverted to VA ECMO or adopted multisite VV ECMO due to the risks associated with the Avalon.^{27,28} Recently, the Crescent RA cannula from Medtronic, with its smallest available size at 13 Fr, has entered the market, potentially expanding available options.

ECMO modalities in the small patient (<10 kg)

Cannulation for VV ECMO in infants under 10 kg is complicated by small femoral vein size, leading to several challenges including difficulty achieving adequate flow, venous congestion and thrombosis.^{15,18} Three principal cannulation strategies have emerged to address these challenges: VA ECMO, VV ECMO with a DLC and VV ECMO by Multisite cannulation. Table 1 summarizes the major advantages and disadvantages of the three strategies.

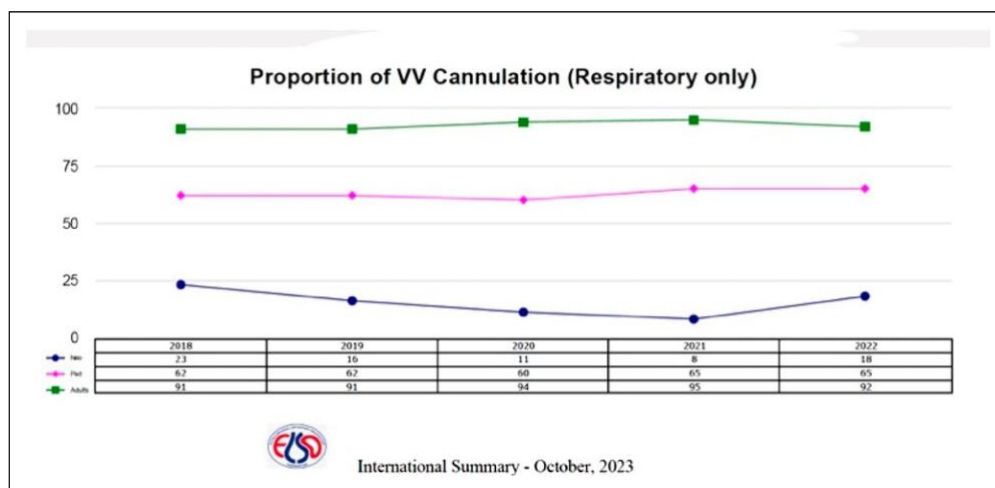


Figure 2. Extracorporeal life support organization. International trend report. October 2023.

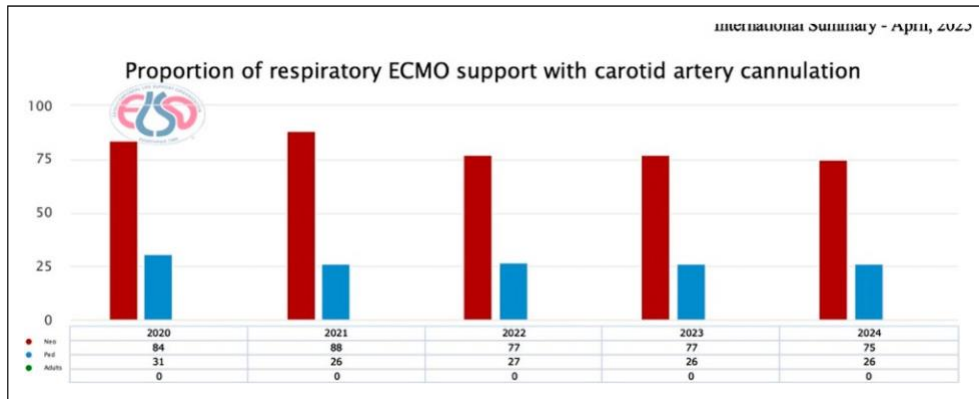


Figure 3. Extracorporeal life support organization. International trend report. April 2025.

VA ECMO via the carotid artery

While technically straightforward and providing cardiac and respiratory support, this approach raises concerns about neurological injury due to carotid artery occlusion.

VV ECMO via the internal jugular vein with a DLC

Avalon cannula. The Avalon bicaval cannula was originally available in sizes as small as 12 French but was prone to kinking due to lack of reinforcement.²⁸ The currently available 13 Fr wire-reinforced version resolves this issue but is limited to infants over 2.5 kg.¹⁰ Cannulation remains technically demanding, with risks

including vascular laceration, cardiac perforation, and malposition.

Proper cannulation technique relies heavily on real-time ultrasound (US) for vessel assessment and size selection.^{11,12} Confirming cannula length before insertion is crucial to ensure the tip reaches the inferior vena cava (IVC). A practical method involves projecting cannula length on chest radiographs from insertion site to the proximal IVC.

Moscattelli et al. described that echocardiographic guidance during cannulation is essential.¹¹ Because the superior vena cava (SVC) and inferior vena cava (IVC) lie in different anatomical planes, guidewire passage into the IVC can be challenging, particularly in neonates. A looping guidewire within the right atrium (RA) or right ventricle (RV) can lead to

Table 1. Key data on pediatric VV ECMO cannulation, including patient weight, cannula size, flow, leg edema, and vein outcomes from various centers.

Cannulation strategy	Venous cannula	Pros	Cons	Weight range
VA ECMO (Carotid-jugular)	Single lumen	Available worldwide Provides circulatory support Easy positioning Rare dislocation	Multi-vessel Carotid sacrifice Risk of neurologic injury Risk of bleeding	All
VV ECMO (Dual lumen – Avalon)	Dual-lumen (13–31 Fr)	Single vessel Avoids carotid use	Not feasible <2.5 kg Risk of dislocation & perforation	>2.5 kg
VV ECMO (Dual lumen – Crescent RA)	Dual-lumen (13–19 Fr)	Single vessel Avoids carotid use Easy positioning Less dislocation	Limited data	<15 kg
VV ECMO (Multisite)	2x single-lumen	Available worldwide Avoids carotid use Easy positioning Rare dislocation	Multi-vessel More recirculation Femoral vein thrombosis	All

perforation during dilation or cannula insertion. They favor the use of a bent “hockey-stick” straight guidewire tip over the standard J-tip, to minimizing right atrial looping.¹¹

Correct cannula placement is critical: Drainage ports must reside in both the SVC and IVC, and the reinfusion port oriented toward the tricuspid valve, to avoid poor drainage or recirculation. Smaller cannulas (<19 Fr) have shorter insertable length (11 to 21 cm), which may limit the reach from the insertion point to the ideal tip position, sometimes requiring a more proximal insertion. This presents an additional challenge and limitation in neonates and small infants.

Percutaneous approaches have been successfully implemented in several centers. Carpenter et al. at Texas Children’s Hospital reported over a decade of safe percutaneous Avalon cannulations without complications.¹³ Similarly, Conrad et al. in Louisiana documented high success and low complication rates using combined ultrasound and fluoroscopy in neonates and infants up to 10 kg.²⁹ Moscatelli et al. in Italy described exclusive percutaneous cannulation in neonates above 3 kg, with surgical backup reserved for vascular complications or anatomical constraints.¹¹

Post-cannulation complications include cannula migration, impairing drainage and reinfusion, and cardiac wall perforation, the most severe complication.¹⁴ Perforation can occur during insertion due to guidewire looping or may be delayed as a result of mechanical erosion by a malpositioned cannula tip. This risk is not theoretical: Speggorin et al. re-reported cardiac tamponade from atrial wall perforation in 6.9% of neonates supported with a 13 Fr Avalon® DLC, requiring emergency sternotomy. These events occurred not during cannulation, but hours to days later, likely due to mechanical erosion at the cavoatrial junction. As a result, the institution suspended use of the Avalon cannula in neonates, citing unacceptable risk in this population despite its benefits in larger children and adults.³⁰ Many centers recommend regular imaging surveillance, including echocardiography every 8 hours and before/after patient mobilization, to detect complications early.

Repositioning under transthoracic echocardiographic (TTE) guidance—using patient positioning (e.g., head flexion, back elevation) and gentle cannula rotation to align the SVC and IVC axes—can correct malposition. If unsuccessful, leaving the tip safely in the right atrium, away from the atrial wall, may reduce perforation risk, though this can increase re-circulation. A large single-center study by Ramaraj et al. showed that routine echocardiography during and after cannulation may help mitigate the risk of severe cannula-related complications such as atrial perforation or pericardial effusion. In their retrospective review of 119 pediatric patients—including 82 under 2 years of age—they found no significant difference in complication rates between atrial and bicaval DLC when frequent echocardiographic monitoring was used.³¹

Crescent cannula. The Crescent™ RA DLC (Medtronic), introduced in 2021, is designed for pediatric VV ECMO patients between 3.5 and 15 kg and is available in 13, 15, and 19 French sizes. Unlike the Avalon, it terminates in the right atrium rather than extending into the IVC, potentially reducing IVC-related perforation and thrombosis risks.

A multicenter retrospective cohort by the Children’s Hospital Neonatal Consortium (CHNC) ECMO Focus Group examined 58 neonates and infants cannulated with the Crescent™ RA cannula from 2021 to 2023, reporting an 84.5% survival to discharge. Cannula malposition occurred in 46.6% of cases, with surgical repositioning required in 29.3%, yet only one major cannula-related death was reported.⁸ In a single-center series at Nationwide Children’s Hospital,⁹ six pediatric patients underwent seven VV ECMO runs using the Crescent™ RA cannula. The cannula provided adequate flows and oxygenation with only one repositioning due to recirculation from initial malposition.

This cannula presents several design advantages⁹ including crescent-shaped lumen allowing for higher flows with lower pressure drop, potentially reducing hemolysis and recirculation; radiopaque markers to assist precise positioning; suture reinforcement ring and

Table 2. Differences between the crescent RA cannula and the bicaval Avalon cannula.

Feature	Avalon cannula (Bicaval)	Crescent RA cannula (RA only)
Cannula tip location	IVC (distal), bicaval	Right atrium only
Drainage ports	SVC + IVC	Right atrium only
Return flow direction	Toward tricuspid valve	Toward tricuspid valve
Positioning challenge	Precise bicaval positioning	Simpler, less precise
Risks	IVC misplacement, perforation	RA wall perforation, arrhythmias
Efficiency	Efficient bicaval drainage	May be less optimal in IVC congestion

Table 3. Available options for venous cannulation according to the patient's weight.

Weight (kg)	Avalon DLC (Fr)	Crescent RA DLC (Fr)	Venous single lumen, neck access (Fr)	Venous single lumen, groin return (Fr)
<2.5	-	-	8-10	8
2.5-3	13	13	8-12	8
3-4	13	13	10-12	8
4-5	13	13	10-12	8
5-8	16	15	12-14	8-10
8-10	16-19	15-19	16-17	12-14

Table 4. Pediatric Multisite VV ECMO cannulation data from multiple centers.

Author (institution)	Years	Nb	Weight (kg)	-Cannula size -side	-Flow -ml/kg/min	Leg edema	Vein at follow-up
Kipfmüller (Bonn)	2017-2021	15	1.8 – 2.7	–8 & 10 Fr –46% left FV	–Adequate –100 to 150	NA	37% Thrombosed
Lillie (Evelina)	2015-2019	11	2.1 – 8.8	8 – 14 Fr 18% left FV	Adequate 126	100%	All ligated Edema resolved
Reitere (Graz)	1989-2016	17	Neonates	NA	NA	NA	NA
Awad (Sydney)	2013-2022	2	<18 kg	NA	Adequate 57 – 90	NA	NA
Klein (Ann Arbor)	1981-1984	8	2.3 – 4.9	NA	Adequate 138	100%	All ligated Persistent edema

collar; and flow dynamics mimicking physiologic venous return ratios to optimize circuit efficiency.

In summary, the Crescent™ RA cannula offers promising improvements for pediatric VV ECMO with fewer IVC-related complications, though high malposition rates necessitates routine imaging (echocardiography, fluoroscopy) during and after insertion.

Table 2 summarizes some of the major differences between the Crescent RA and the bicaval Avalon. Table 3 shows the available options for venous cannulation.

Multisite VV ECMO

This approach revisits the traditional avoidance of femoral veins in infants under 2 years. Early work by Bartlett demonstrated feasibility but did not clarify clear benefits over VA ECMO. Recent reports from centers in Bonn,³² Evelina London,¹⁵ and Graz³³ have shown successful use in neonates, even if the weight is under 2 kg. Jugular-femoral cannulation configurations provided adequate flow, with no adverse limb outcomes despite femoral or iliac thrombosis. MacLaren (2021) highlighted this strategy's clinical importance amid a global shortage of DLC and technical limitations of their placement in neonates. He emphasized that femoral vessels, though previously avoided due to concerns about thrombosis and vessel hypoplasia, can safely serve as return sites when paired with jugular drainage.¹⁸

Lillie et al. reported that nine out of 11 neonates survived with this two-site VV ECMO strategy, without major vascular complications after 1 year.¹⁵ This approach preserves carotid arteries, potentially reducing neurologic risk compared to VA ECMO. MacLaren highlighted some challenges affecting cannula performance, such as recirculation, ductus venosus interference, and persistent fetal circulation, which are especially relevant in neonates.¹⁸

Overall, multisite VV ECMO, when conducted by experienced teams with meticulous technique and monitoring, is a safe and effective alternative in infants <10 kg. Table 4 summarizes the reported series of multisite VV ECMO. Table 3 shows the available options for venous cannulation according to the patient's weight: DLC sizes were taken from charts found on the Internet, based on recommended flows and acceptable pressure drops^{34,35}; single lumen neck and groin cannula sizes were taken from the series of Lillie et al. and Kipfmüller et al. describing their experience in multisite VV ECMO.^{15,32}

Conclusion and future directions

Recent advancements have significantly expanded the use of VV ECMO in neonates and infants under 10 kg. Enhanced DLC designs, such as the Crescent RA, along with improved imaging techniques like real-time

ultrasound and echocardiography, have made cannulation safer and more precise. Increased familiarity among clinicians has further driven successful outcomes and broader adoption.

As the field evolves, there is growing interest in developing smaller, shorter cannulas tailored to neonatal anatomy. These could optimize flow rates, reduce thrombogenicity, and minimize mechanical stress on vessels. Additionally, multisite VV ECMO—using jugular and femoral cannulation—has emerged as a valuable alternative when dual-lumen access is not feasible. Early data from expert centers show promising survival and limb preservation rates with this strategy.

The role of surgical expertise remains central in both cannulation and complication management. As these new tools and approaches are integrated into practice, collaborative multicenter research will be essential to refine protocols, validate outcomes, and minimize risks—particularly neurologic and vascular complications. Ultimately, the ongoing evolution of VV ECMO, guided by thoughtful innovation and clinical vigilance, holds promise for improving both survival and long-term outcomes in this vulnerable patient population.

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