Published in: Perfusion
DOI: 10.1177/02676591251407295
Status : Postprint (Author's version)

Peripheral veno-arterial ECMO cannulation in children: Review of the relevant ELSO publications

Jana Assy[1], Matteo Di Nardo[2] and Issam El Rassi[3]

Abstract

Background: Peripheral veno-arterial (VA) extracorporeal membrane oxygenation (ECMO) cannulation in children poses a significant clinical challenge due to wide variations in body size, vessel caliber, and risk profiles.
Purpose: This literature review examines current cannulation practices in pediatric patients.
Research design Study sample & Data collection: The study analyzed large datasets from the Extracorporeal Life Support Organization (ELSO) registry, focusing on neurologic and limb complications associated with carotid versus femoral artery use.
Results: Despite general recommendations favoring carotid cannulation in children under 15–20 kg and femoral access in larger, ambulatory patients, ELSO data show a persistent reliance on carotid cannulation even in older children. In four major ELSO studies, carotid use ranged from 45% to 94% among children over 5 years of age. Neurologic complication rates varied widely, from 7% to 23%, with some studies linking carotid access to higher risk of CNS injury, while others found no significant difference. Femoral cannulation, although theoretically safer neurologically, carried notable risks of limb ischemia—reported between 7.5% and 20%—and potential need for vascular interventions or amputations.
Conclusions: This review highlights the lack of standardized practice and the influence of local expertise, anatomical variability, and data limitations. It also underscores the need for clearer definitions and better reporting in future studies. While carotid cannulation remains prevalent across age groups, growing evidence of limb complications with femoral access invites reconsideration of the "transition point" in pediatric ECMO cannulation strategies. Until more definitive data emerge, individualized decision-making guided by patient characteristics and institutional experience remains essential.

Keywords

pediatric ECMO, arterial cannulation, carotid artery, femoral artery, neurologic complications, limb ischemia, ELSO registry

Introduction

Deciding on the best strategy to cannulate a child for peripheral veno-arterial (VA) extracorporeal membrane oxygenation (ECMO) can be difficult. Firstly, children can vary significantly in weight, yet all are susceptible to childhood diseases, complicating the standardization of cannulation techniques. Secondly, there is often a size conflict between cannula and vessel: A certain size cannula is needed to achieve adequate flows and this is often larger than the vessel can easily accommodate. But most importantly, the decision on a specific cannulation site involves weighing potential risks, such as increased brain injury with carotid cannulation,[1–5] versus introducing limb ischemia with the use of the femoral artery.[5–8]

For the above reasons, most pediatric ECMO teams follow two widely recognized "rules" for arterial cannulation:

- First: Using the carotid artery in children above 15 kg may increase the risk of neurologic injury[1,2,5,9–11] (Figure 1).
- Second: It is possible to use the femoral artery in ambulatory children above 15 kg; however, the risk of neurologic injury may be traded against an

[1]Department of Pediatrics, University Hospital of Liege, Liège, Belgium
[2]Pediatric Intensive Care Unit, Bambino Gesu` Children's Hospital, Rome, Italy
[3]Pediatric Cardiac Surgery, Al Jalila Children's Hospital, Dubai, Dubai

Corresponding author:
Jana Assy, Department of Pediatrics, University Hospital of Liege, 1, Avenue de l'Hopital, Liège 4000, Belgium.
Email: Jana.assy@chuliege.be

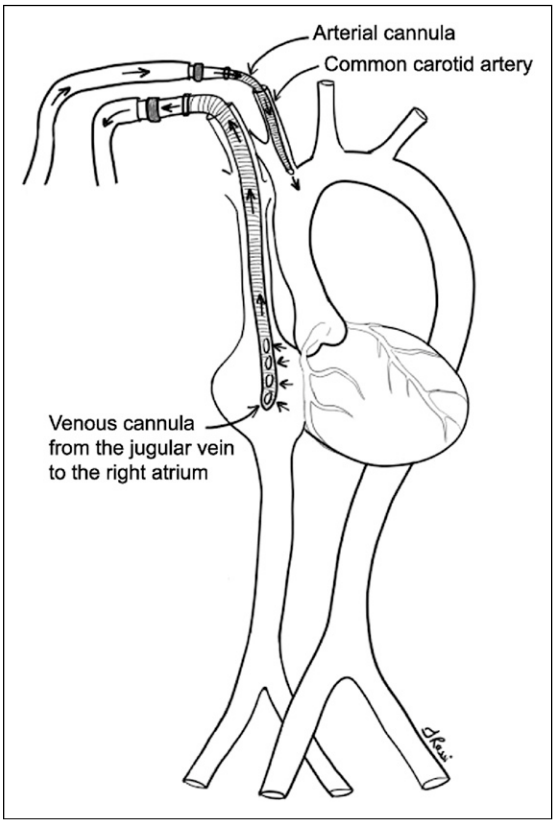

Figure 1. Jugular vein to Carotid artery Veno-Arterial ECMO.

increased risk of limb ischemia and the challenging reconstruction a small femoral artery[1,5,12] (Figure 2).

The Extracorporeal Life Support Organization (ELSO) registry provides valuable insights into global cannulation practices.[13] Despite limitations inherent to retrospective studies, the registry is the largest comprehensive database to examine neurologic and limb complication rates associated with different cannulation sites. Four large studies based on the ELSO database were reviewed. They included large numbers of children on VA ECMO with peripheral cannulation: Johnson et al.,[12] 15.434 patients; Teele et al.,[14] 2.039 patients; Rollins et al.,[15] 1.632 patients; and Di Gennaro et al.,[9] 1.518 patients.

Studying the literature cannot claim to clear the grey areas and the dilemma of arterial cannulations in children beyond 15 kg. However, by reviewing the current practices and the reported neurologic and limb complications, we can better rediscuss the established cannulation rules.

Methods

The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines; however, this study is not a meta-analyses or a systematic review, but a literature review to evaluate the current prevailing cannulation practices for peripheral VA ECMO. VV ECMO in children was addressed recently in this journal (doi.org/10.1177/02676591251379622). We searched the electronic databases PubMed/Medline, Scopus and Web of Science, from inception to June 2025. Search strategy combined controlled vocabulary using Medical Subject Headings (MeSH Terms) and non-MeSH search terms such as extracorporeal membrane oxygenation, ECMO, extracorporeal life support, ECLS, venoarterial, VA ECMO, central nervous system, CNS, neurologic, carotid, neck, ischemia, vascular, lower extremity, limb, groin, injury, complications, and morbidity. Boolean operators ("AND," "OR") were used to combine terms. After testing and finalizing the PubMed search strategy, we translated it for use in other databases, adjusting it as needed. We used filters to exclude the types of documents that we did not plan to use, such as case reports, non-peer-reviewed material, meeting abstracts, proceeding articles, editorials, books, notes, and so forth. Additional exclusion criteria included non-English language, non-human subjects, and patients above 18 years of age.

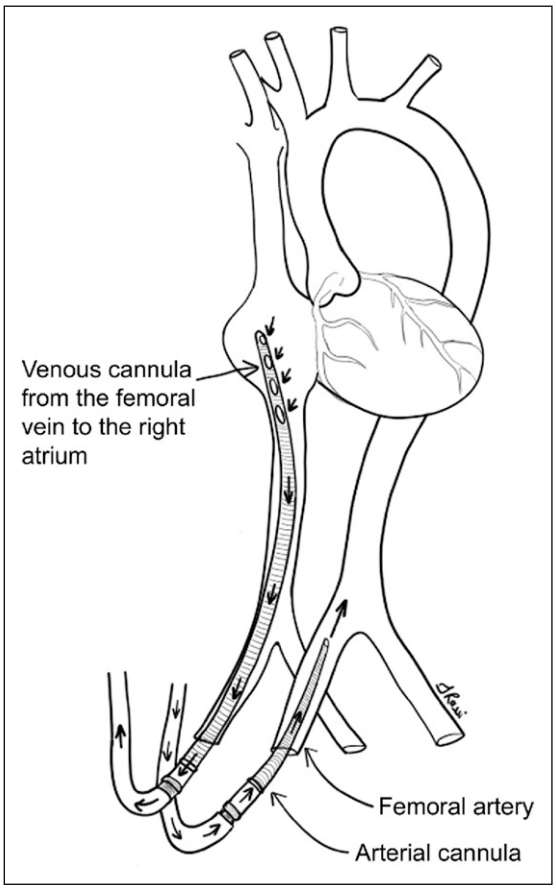

Figure 2. Femoral vein to Femoral artery Veno-Arterial ECMO.

Table 1. Carotid and Femoral cannulation practice in large series from ELSO registry.

The circles demonstrate the ongoing trend in carotid cannulation even in older pediatric and adolescent patients aged 5–20 years.

Author	Number	Age Groups					
		Neonates Nb (%)	1 – 11 months Nb (%)	1 – 5 years Nb (%)	6 – 12 years Nb (%)	13 – 17 years Nb (%)	
Johnson[12] 1989-2013	**15,434**	9,567	2,806	1,434	767	860	-
Carotid	14,517	9008 (94%)	2624 (94%)	1358 (95%)	721 (94%)	806 (94%)	-
Femoral	917	559 (6%)	182 (6%)	76 (5%)	46 (6%)	54 (6%)	-
		Neonates	1 – 12 months	1 – 5 years	5 – 18 years		
Teele[14] 2007-2008	**2,039**†	1,807	582	281	307		-
Carotid	1,921	1276	316	186	143		-
Femoral	118	NA	NA	NA	NA		-
			1 – 12 months Nb (%)	1 – 5 years Nb (%)	5 – 10 years Nb (%)	10 – 15 years Nb (%)	
Rollins[15] 1993-2007	**1,632**		843	441	140	208	-
Carotid	1,516	-	834 (99%)	426 (97%)	123 (88%)	133 (64%)	-
Femoral	116	-	9 (1%)	15 (3%)	17 (12%)	75 (36%)	-
					6 – 10 years Nb (%)	11 - 20 years Nb (%)	21 – 40 years Nb (%)
Di Gennaro[9] 2000-2012	**1,090**‡		-		360	730	428
Carotid	602		-		271 (75%)	331 (45%)	38 (9%)
Femoral	488		-		89 (25%)	399 (55%)	390 (91%)

Abbreviations – NA: not available; Nb: number

†The Number column lists 2039 (total number of patients with VA-Carotid + VA-Femoral; excluding patients with VA -Aorta). However, for age distribution, Teele et al. did not mention the number of patients with VA-Femoral in each age group; thus the adjacent figures of 1807, 582, 281 and 307 represent total number of patients with VA-Carotid + VA-Femoral + VA-Aorta in each age group. For the same reason, percentages cannot be calculated, as the denominator is unknown.

‡The numbers in the cross-hatched column (patients 21 to 40 years) were excluded from the calculations shown for the 2 patient-groups below 20 years.

Carotid cannulation

Following the above general exclusion criteria and removal of duplicates, the initial harvest of 6423 papers was narrowed down to 269 studies. Two independent reviewers (JA & IER) screened titles and abstracts for relevance and 201 records were further excluded leaving 68 articles. Full texts of these potentially eligible studies were then as-sessed, and disagreements were resolved by consensus. The inclusion criteria were clear: Studies that exclusively analyzed the ELSO registry, with the aim of evaluating the association between the site of arterial cannulation and neurologic injury in peripheral VA ECMO, and assessing whether this relationship is influenced by age. Studies were considered eligible if they included clear coherent data about outcomes, complications, technical aspects, or other relevant endpoints. Upon full-text review, 64 articles were excluded: 62 for not meeting inclusion criteria and two for insufficient data. Finally, only four studies provided the required inclusion criteria.

Femoral cannulation

The initial harvest of 3864 papers was similarly narrowed down to 150 studies. The same reviewers screened titles and abstracts for relevance and 132 records were further excluded leaving 18 articles for full text assessment. Inclusion criteria were ELSO and non-ELSO studies about femoral cannulation and related management and complications. Non-ELSO studies were included because data relative to limb complications were scarce before 2013 in the ELSO registry.[5,8] Following full text assessment, eligibility criteria were the same as above, and 11 articles were excluded: five for not meeting inclusion criteria and six for insufficient data. Finally, seven studies provided sufficient data for inclusion.

Results

Cannulation sites

The most extensive evidence comes from the series of Johnson et al. including 28,000 patients under 18 years.[12] Neonates and

Table 2. Neurologic complications according to cannulation site in large series from ELSO Registry.

		Overall CNS injuries[a]		CNS infarct		CNS hemorrhage	
Author	Number	Prevalence	*p* value	Prevalence	*p* value	Prevalence	*p* value
Johnson[12,b]	15,434	19.5%[c]	$p > 0.05$	4.5%[c]	$p > 0.05$	NA	NA
1989-2013							
Carotid	14,517	19.4%		4.35%			
Femoral	917	20.1%		5.13%			
Teele[14]	2,039	22%	$p = 0.001$[a]	NA	NA	NA	NA
2007-2008							
Carotid	1,921	23%					
Femoral	118	15%					
Rollins[15]	1,632	11.8%	NS	5.7%		6.1%	
1993-2007							
Carotid	1,516	11%		6%	NS	7%	$p < 0.05$[a]
Femoral	116	7%		5%		2%	
Di Gennaro[9]	1,518	10%	$p > 0.05$	74 (4.9%)		78 (5.1%)	
2000-2012							
Carotid	640	13.9%		7.3%	$p < 0.001$[a]	6.6%	$p = 0.69$
Femoral	878	7.1%		3.1%		4.1%	

Abbreviations - CNS: Central nervous system; NA: not available; NS: Not Significant.
[a]Overall CNS injuries are defined as follows: (Johnson) seizures, brain death, intracranial hemorrhage and ischemic stroke, (Teele) seizures, intracranial hemorrhage and ischemic stroke, (Rollins) central nervous system bleeding or infarct, and (Di Gennaro) central nervous system bleeding or infarct.
[b]Following multivariate analysis, adjusting for age, gender, weight, race, in addition to factors affecting the severity of illness (oxygenation index, pre-ECLS arrest, and support type).
[c]19.5% and 4.5% are not the complication rates for the 15,434 cases. The figures represent the complication rates for all cases (28,581 cases) involving VA-Carotid, VA-Femoral, VA-Aortic, and VV. The difference was however non-significant compared to carotid and femoral.

infants constituted 80% of all patients. Among the 22,000 patients on VA ECMO, there were 15,000 patients with only peripheral cannulation. The analysis of this subgroup showed remarkably similar practices in all ages, with 94% of carotid cannulation across all age groups, defying expectations of differences between teenagers and neonates (Table 1).

The second series from Teele et al. showed that although carotid artery usage progressively decreased with age, a number of children above 6 years were still cannulated via the carotid artery.[14] The authors noted an increase in femoral cannulations with age, but specific numbers are not provided because the femoral artery and aorta were combined as the alternative to carotid for the regression analysis. For comparison purposes and to highlight variations in practices, this study is summarized in Table 1 along with the other series.

Another study from Rollins et al. spanning 15 years, focusing on ECMO for primary pulmonary indication exhibited a similar persistence in carotid use in 88% of children aged 5.1 to 10 years.[15] Femoral cannulation increased progressively, but only to 36% in patients above 10 years.

The final series from Di Gennaro et al. included only patients aged 6 to 40 years, likely excluding younger children where carotid cannulation is usually intuitive.[9] This analysis demonstrated the expected decline in carotid cannulation from 75% in the 6–10 years age group, to 45% in the 11–20 years age group (Table 1).

Patients above 20 years were not included in our analysis and conclusions. However, it is interesting to note that 9% of 428 adults were cannulated through the carotid artery.

Summarizing Table 1, carotid use ranged from 45% to 94% in children above 5 years, extended to teenagers, and was still used, though rarely, in young adults.

Femoral artery use was rare below 5 years, occurring in less than 6% of cases.

Cannulation site complications: Neurologic injury

Central nervous system (CNS) injury was analyzed in the same four large series discussed above. The study by Johnson et al.,[12] the largest investigation into cannulation rates in pediatric ECMO, did not identify any significant differences in the adjusted rate of overall neurologic complications or CNS infarcts between carotid and femoral cannulation. These findings stand in contrast to those of the other three series. The overall rate of neurological injuries in the study was 19.5%, and the rate of CNS infarcts was 4.5% (Table 2).

Teele et al.[14] reported a slightly higher prevalence of neurologic injury (21%), and specifically highlighted a significant difference based on the site of cannulation. Patients cannulated via the carotid artery had a significantly higher rate of CNS injury compared to those cannulated via

Table 3. Femoral cannulation in children.

Author	Institution	Years	Number	Age Range	Ischemia[a] Nb (%)	Amputation Nb (%)	DPC Nb (%)
Shah[7]	Ann Arbor	2015–2022	24	5–20 years	5 (21%)	0%	18 (75%)
Buyukgoz[18]	LeBonheur	2019–2021	22	4–18 years	3 (14%)	1 (4.5%)	17 (73%)
Garcia[16]	ELSO registry	2012–2017	429	12–18 years	32 (7.4%)	NA	104 (24%)
Schad[6]	Columbia	2005–2015	31	4–22 years	6 (19%)	3 (10%)	23 (74%)
Kurkluoglu[17,b]	Washington	2006–2013	17	7.5–16 years	4 (24%)	0%	NA
Gander[8]	Columbia	2000–2010	21	2–22 years	4 (19%)	2 (10%)	9 (43%)
Weighted averages (95% confidence interval)		2000–2022	544pts	2–22 years	9.9% (7.4%–12.4%)	5.2% (1.2%–9.3%)	32.4% (28.5%–36.4%)

Abbreviations - NA: not available; Nb: number; DPC: distal perfusion cannula.
[a]Any vascular surgery, fasciotomy or amputation.
[b]Kurkluoglu et al. show the age range as interquartile range. The other studies show the age ranges as minimum – maximum.

the femoral artery (23% vs 15%, $p = 0.001$). This finding was consistent across all age groups.

The third report by Rollins et al.[15] revealed a low overall rate of CNS injury of 11.8%. There was a significantly higher incidence of CNS hemorrhage in the carotid group compared to the femoral group (7% vs 2%, $p < 0.05$). The rates of CNS infarct were similar (6% vs 5%) across all the age groups, except for the children above 10 years of age (9% vs 1%, $p < 0.05$). The presence of either injury was not significantly different (11% vs 7%).

In the final study by Di Genaro et al.[9] focusing on children above 6 years and young adults, there was a 10% incidence of brain injury. The study found a significant prevalence of ischemic stroke in patients cannulated via the carotid artery (7.3% vs 3.1%) ($p = 0.001$), consistent across all ages.

Cannulation site complication: Limb ischemia

Table 3 consolidates data from various studies and 500 patients spanning from 2000 to 2022. As stated in the "Methods" section, we included non-ELSO series in lower limb ischemic complications because this complication was included in the ELSO registry only after 2013. In this table, we grouped under ischemia any vascular intervention, fasciotomy or amputation. The series from the ELSO registry was the largest and included more than 400 patients.[16] "It reported a very low rate of lower limb ischemia (7.5%); however, data related to amputation was not available, not recorded in the database.

The five other small series included 108 patients in total and reported limb complications ranging from 14% to 24%.[6–8,17,18] The rates of reperfusion catheter insertion ranged from 25% to 75% and the amputation rates ranged from 0% to 10%.

Discussion

ELSO guidelines and the existing literature provide excellent guidance for ECMO peripheral arterial cannulation in children. In some age ranges, however, this remains a debate even among experienced teams.[1–5] The discussion revolves around neurologic complications related to the use of carotid arteries (Figure 1) and lower limb ischemic complications following cannulation of femoral arteries (Figure 2). Neurologic complications of ECMO can be severe and permanent and are a well-documented cause of mortality on ECMO[9,14]; thus, the weight of 15 kg to 20 kg is considered by most groups as the limit below which carotid artery cannulation doesn't increase the risk of CNS injury.[1,2,5,9] Beyond this weight, in ambulatory children, the femoral arteries can be used for ECMO reinfusion; however, this carries a significant risk of ischemic lower limb complications in smaller children, without a well-recognized reduction in the overall risk of neurologic complications.[1,10–12] For these reasons, most groups will wait longer than the above limits before using the femoral arteries. This intuitive practice of avoiding the femoral

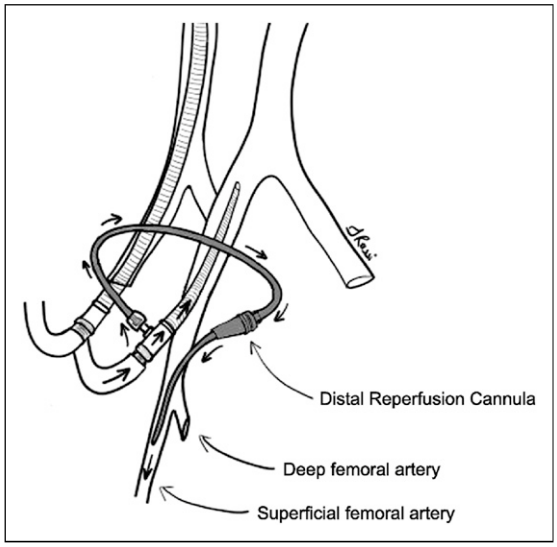

Figure 3. Distal Perfusion Cannula (DPC) for femoro-femoral veno-arterial ECMO.

arteries was in fact much more prevalent than expected when we analyzed large series from a considerable database such as the ELSO registry. More than 46% of children above 5 years are cannulated via the carotid artery, and this percentage reached 94% in the largest cohort (Table 1). It is important to note that Johnson's series reporting 94% of carotid cannulation across all age groups is the largest to date, including 15,000 patients with peripheral cannulation, and probably includes the children from the three earlier series we analyzed in Table 1. This makes its conclusions highly reflective of the prevailing practice favoring carotid use in older children. However, we must consider an important bias favoring carotid use in the analyzed data: more than 75% of the total number of VA ECMO patients in the four studies combined are less than 1 year old and they wouldn't have been considered anyway for femoral cannulation.

A North-American survey added insight into contemporary everyday practice through two questions relevant to this discussion[19]: One question about the use of the femoral arteries in various age groups, and the other about arterial cannulation for a 20 kg, 7 year-old patient. Responses to the survey corroborated the above findings: No surgeon used the femoral artery below 3 years, with 63% of the surgeons preferring neck cannulation for the 7 year-old patient. Femoral artery cannulation increased less than expected with age, from 9.6% in the 3-to-5 age group, to 41.5% only in those between 5 and 12 years. In North America, 80% of surgeons involved with ECMO cannulation are pediatric general surgeons, more familiar with non-cardiac disease and carotid cannulation; more than 90% prefer neck cannulation in children under 5 years of age, largely due to limited training in femoral artery repair, concerns about the risk of limb ischemia, and the technical difficulty of inserting a distal perfusion cannula in small, vasospastic arteries[19] (Figure 3).

Carotid approach for VA ECMO relates intuitively to brain injury, but the debate still rages around the impact of the use of carotid artery on neurologic injury, especially in neonates and infants.[20–22] There are several confounding factors making data analysis extremely challenging, including the severity of the initial disease, hemodynamic instability, cardiac arrest, cyanotic cardiac anomalies, sedation practices and the ligation or reconstruction of the carotid artery following decannulation.[14,15] In addition, lack of accurate detail about severity and type CNS injury may exaggerate or underestimate the extent of neurologic complications, especially if seizures, cerebral edema, uncertain transient ischemic events and hypoxic brain injury are included, excluded, or mislabeled as stroke or hemorrhage in the analyzed data. Moreover, it's worth noting that intracranial hemorrhage is reported to be more frequent in patients on VV ECMO - where the carotid isn't involved - which challenges the assumption that the cannulation site is the primary culprit.[23] Multivariate analysis may or may not isolate the impact of all these confounding factors.

Anatomic and physiologic factors observed in animal and human studies add another layer of complexity related to neurologic outcomes associated with carotid cannulation. When the carotid artery is used, bilateral intracranial blood supply is restored within 3–5 min by a compensatory increased flow in the left carotid artery, and by several extra and intracranial collaterals through the circle of Willis.[24,25] In addition, unlike adults, pediatric patients are not affected by atherosclerosis, which might imply a lower baseline risk of stroke from carotid cannulation. Thus, sufficient bilateral blood supply for both hemispheres has been shown to be maintained following carotid use.[25–27] Correspondingly, studies have demonstrated that the side of the CNS injury is not always correlated to the side of the used carotid artery, implying that other factors may be more important than cannulation site.[14] On the other hand, an incomplete circle of Willis is found in 6% of the population, an anatomic variation that may result in stroke on the ipsilateral side.[27]

The above confounding factors have resulted in conflicting results: Overall CNS injuries with carotid cannulation varied between 11% and 23%. This is a relatively wide interval with no clear reasons explaining variations: The studies analyzed herein cover overlapping eras, from the same registry and all include large pediatric VA ECMO cohorts. One explanation for these wide differences is one of the limitations of this paper: The ELSO registry is a voluntary retrospective registry and data recording may be affected by patient selection, data omission, or the individual institutional criteria for the definition and diagnosis of CNS complications. Stroke and hemorrhage are universally considered as neurologic complications of ECMO, while seizures and brain death are not unanimously attributed only to ECMO, and may be due to the primary illness, previous cardiac arrest or critical hemodynamic condition.[9,14] However, if we examine also non-ELSO reports, we can find similar wide variations in the definitions and in the reported CNS injury rates, between 10% and 50%.[28]

Determining which results accurately represent the truth remains a challenge in ECMO practice. Most studies lack in accurate and granular details about severity and type CNS injury or limb complications. Thus, to gain a more comprehensive understanding of the cannulation dilemma, it is important to similarly analyze femoral cannulation data. By elucidating the nuances of femoral cannulation and comparing its outcomes with those of other cannulation sites, we can refine our understanding of optimal cannulation strategies in pediatric ECMO.

The leg's anatomy plays a key role in the vascular complications encountered during ECMO. Muscle groups in the leg are enclosed in tight compartments bounded by fascia and bone, which limits their ability to expand. This rigidity makes them vulnerable to ischemia and elevated pressures. A sustained intra-compartment pressure of 30 mmHg for 6 hours can cause irreversible damage,

including muscle necrosis, nerve injury, and rhabdomyolysis.[29,30]

Several interconnected mechanisms underlie ECMO-related vascular complications. These include mechanical obstruction by the cannula, endothelial injury, thrombosis, platelet activation, and systemic coagulation triggered by ECMO-induced inflammation.[31] Additionally, compromised collateral circulation, accidental blockage of the profunda femoris or internal iliac arteries, and the use of vasopressors in low-flow states exacerbate the risk. Over time, fibrin buildup and thrombosis around the cannula may dislodge and embolize, leading to distal arterial occlusion in the tibial or pedal vessels.[32] Some of these mechanisms contributing to ischemia were clinically investigated; no statistically significant correlation could be identified between lower limb ischemia and cannula-to-BSA ratio or vasopressor administration.[8] Finally, cannulation, cannula misplacement and decannulation can also result in iatrogenic trauma, including arterial dissection, perforation, or avulsion, potentially causing retroperitoneal bleeding, hematomas, or pseudoaneurysms.[33–35] For this reason, smaller cannula sizes are generally selected for femoral artery cannulation in children, both to match the reduced vessel diameter and to limit the potential for iatrogenic damage, raising concerns about achieving adequate flow rates in this "grey area" patients. In a large review on 429 VA ECMO patients, the risk of limb ischemia was decreased with smaller arterial cannulas (<15-16Fr), without sacrificing flow capacity, and was independent of distal perfusion catheters (DPC) placement.[16]

Use of DPC in VA ECMO varies widely.[36,37] Properly placed antegrade or retrograde DPCs—typically four to 7 Fr—inserted under ultrasound guidance and connected to the arterial cannula's side port, help maintain downstream perfusion and reduce limb ischemia.[6,37,38] Most studies show that prophylactic DPC can lower acute limb ischemia. Shad et al. showed that prophylactic DPC lowered acute limb ischemia incidence by 59% (from 29% to 12%).[6] A systematic review analyzed 15 studies and concluded that DPC lowered limb ischemia incidence by 40% (from 11.7% to 7.1%); the odds of developing limb ischemia was 1.93 (95% CI, 1.17–2.47; $p = 0.03$) when patients did not have a DPC.[38] Reactive DPC inserted following the appearance of limb ischemia is successful in limb salvage only in 50% of the cases.[6] The use of DPC appears to impact overall survival and correlated with a slight reduction of mortality (regression coefficient = 0.0019, $p = 0.0199$).[38] We believe that the wide variations in DPC insertion is due to the influence of adult practice: In adult patients, monitoring of the limb and insertion of a "reactive" DPC cannula in a large artery is less challenging. Some researchers have sought to establish criteria to determine which patients require DPC. When the measured mean arterial pressure in the superficial femoral artery was under 50 mm Hg in an adult cohort, a DPC was inserted, and no cases of limb ischemia were reported.[39] In another investigation, near-infrared spectroscopy (NIRS) decreased more than 35% from a baseline following insertion of the ECMO cannula, but returned to baseline following the placement of a DPC.[40] While promising, the application of these criteria has yet to be explored in pediatric patients. Common monitoring strategies in children include hourly capillary refill assessment, hourly evaluation with handheld Doppler, continuous pulse oximetry, and near-infrared spectroscopy (NIRS), often used in combination to enhance detection of limb perfusion issues.[8]

The literature review on femoral cannulation presents significant challenges. An illustrative example is the early series by Gander et al., still cited today by every ECMO study about femoral cannulation.[8] This series reported a 52% incidence of ischemic lower limb complications associated with femoral artery cannulation. However, their definition of ischemic complications included any intervention, such as the use of a reperfusion cannula, leading to an inflated complication rate. A precise analysis reveals a true ischemic complication rate of only 19% (Need for vascular surgery, fasciotomy or amputation). This figure was corroborated by a subsequent series by Shad et al. from the same institution, which reported the accurate 19% rate among a larger patient cohort.[6] Two other series from Ann Arbor[7,18] covered different eras and patient populations, but the latest one documented a similar 20% incidence of ischemic limb complications, with no reported amputations in the latest study.[7] The largest dataset originates from the ELSO registry, which began recording limb ischemia in 2013.[16] This registry reported a surprisingly low ischemia rate of 7.4%, with unspecified amputation rates. The unexpectedly low incidence highlights the limitations inherent to retrospective studies, warranting cautious interpretation, akin to the scrutiny applied to the initial 52% complication rate reported by Columbia.[8]

Does the cannulation site impact mortality? It is well established that neurological injury is a major determinant of outcome, with overall hospital mortality reaching 70% among patients who sustain CNS infarction or hemorrhage, compared with 40% in those without CNS complications.[15] These findings might suggest that carotid artery cannulation is associated with higher mortality on ECMO. However, large series have demonstrated that carotid use is actually associated with significantly lower in-hospital mortality rates compared with femoral cannulation (44%–49% vs 59%).[14,15] Similarly, brain death has been reported to occur significantly less frequently with carotid cannulation than with femoral artery cannulation (6% vs 11%–13%).[14,15] These findings may in part be explained by the higher severity of illness, greater frequency of pre-ECMO cardiac arrest, and increased ECPR cases in the femoral group.[9,14,15] In addition, femoral cannulation poses unique neurological risks, as retrograde flow in the aorta may lead to upper body hypoxemia when myocardial function is

preserved but pulmonary function remains poor, potentially exposing the brain to deoxygenated blood and precipitating CNS injury.

Finally, no study on ECMO-related complications events can be considered complete without addressing the critical role of anticoagulation (AC), given its pivotal influence on the outcomes of ECMO therapy. There remains a significant lack of high-quality evidence regarding optimal AC targets, appropriate monitoring assays, and transfusion strategies in patients receiving ECMO support.[41,42] This evidence gap directly impacts neurologic, and possibly limb complications.[41] The development of evidence-based guidelines is not feasible without large-scale, multicenter randomized controlled trials that correlate bleeding and thrombotic events with specific anticoagulation strategies. The BATE study has demonstrated a strong association -through multivariable logistic regression models-between the treating hospitals and the occurrence of bleeding and thrombotic complications on a large cohort including 514 pediatric patients.[41] Notably, laboratory monitoring strategies for managing anticoagulation were highly variable between the eight sites, reinforcing the fact that each center operates with its own AC protocols.

Such heterogeneity not only prevents meaningful comparisons across institutions but also obstructs the creation of unified, evidence-driven protocols. Due to the lack of reliable correlation between commonly used laboratory assays and the clinical effects of anticoagulants such as heparin, clinicians often diverge from standardized approaches, relying instead on individual experience or institutional precedent.[43] This variation in practice likely contributes to the persistently high incidence of bleeding and highlights the urgent need for standardized anticoagulation monitoring and management in ECMO care.

Limitations

Because this review draws entirely from ELSO Registry–derived publications, its findings must be interpreted with caution. Such reliance introduces an inherent selection and reporting bias, as the registry captures data predominantly from centers that actively participate in ELSO reporting. These are often large, high-volume, or academically engaged institutions, which may not fully reflect the practices, outcomes, or challenges encountered in smaller or less specialized programs. Consequently, the evidence presented may overrepresent centers with greater expertise or resources, potentially limiting the generalizability of the conclusions to the broader ECMO community. Moreover, significant variation in clinical practices—particularly in anticoagulation management—as well as inconsistencies in data quality and definitions, can lead to underreporting of complications and obscure nuanced clinical decision-making. This is especially evident in the case of neurologic complications, where factors such as location, laterality, and long-term outcomes are often inconsistently documented across centers and may evolve over time. Regarding limb ischemia, the registry lacked sufficient data on the use of distal perfusion catheters or other techniques aimed at preserving limb viability in patients who underwent femoral artery cannulation. As a result, approximately 25% of potentially eligible patients could not be analyzed. Furthermore, this evaluation does not reflect the latest advancements in ECMO technology, clinical practice, or the increased expertise that has developed over time.

These limitations must be considered when interpreting findings or deriving practice recommendations from the registry. However, the reports generated from this dataset—authored by recognized ECMO experts and endorsed by ELSO—carry significant authority and continue to shape international guidelines and clinical standards, making the registry a cornerstone of ECMO research and benchmarking despite its biases. Despite the noted limitations, we believe this cohort serves as a representative sample of ECMO utilization. The ELSO registry offered a large dataset that enabled meaningful conclusions to be drawn—insights that would have been difficult to achieve with smaller patient populations.

Conclusions

What can we conclude and how can we clear at least part of the grey area in pediatric arterial cannulation? The evidence concerning the association between carotid artery use and neurologic injury remains conflicting, both in ELSO and non-ELSO reports, primarily due to two factors; firstly, the majority of studies are retrospective. Secondly, available data on the severity and type of neurologic and limb complications are often incomplete and inaccurate. Furthermore, there is compelling evidence of significant lower limb complications associated with femoral artery use, at least equal to the 10% reported in large adult series.[8,43]

As highlighted by Woods in a previous commentary, it is essential to distinguish between a minor stroke with no functional deficits at 6 months and permanent hemiplegia in a child; and the latter cannot be compared to a below-knee amputation following leg ischemia.[4]

What observations can be drawn?

- For children weighing less than 15–20 kg (between 3 and 5 years old), current practice and informal recommendations advocate for neck cannulation, supported by existing literature. In this age group, the small size of the femoral arteries increases the risk of arterial injury during cannulation, ischemia during the ECMO run, and significant challenges in arterial repair following decannulation.

For patients above 20 kg, there are no definitive data or specific recommendations establishing an age

threshold for the transition to femoral artery cannulation. Several factors can influence this decision, perhaps influenced by adult data showing elevated stroke rates with acute carotid occlusion. These factors include anatomical variations in neck or femoral vessels, an incomplete circle of Willis, prior neurologic injuries, and the availability of an experienced vascular surgeon for femoral artery decannulation and reconstruction. Current practice in children above 20 kg reveals a striking contrast to expectations: The carotid artery is utilized in over 75% of children aged 5–10 years and in at least 45% of those above 10 years. The neurological consequences of this practice remain unclear, and the literature provides mixed evidence regarding the association between carotid use and brain injury in this age group. These observations could indicate future research directions and promote collaborative multicenter studies.

Ultimately, the choice of cannulation site in children remains deeply nuanced and must weigh physiologic rationale, anatomical context, patient size, and institutional expertise—often guided as much by experience and instinct as by hard data.

ORCID iDs

Jana Assy https://orcid.org/0009-0005-9774-3525
Matteo Di Nardo https://orcid.org/0000-0003-0051-8080
Issam El Rassi https://orcid.org/0000-0003-3850-8769

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Peek G, Chavez I, Hackmann AE, et al. Cannulation. In: MacLaren G (ed). *Extracorporeal Life Support: The ELSO Red Book*. 6th ed. Extracorporeal Life Support Organization, 2022, pp. 47–64.
2. Brown G, Moynihan KM, Deatrick KB, et al. Extracorporeal Life Support Organization (ELSO): guidelines for pediatric cardiac failure. *ASAIO J* 2021; 67(5): 463–475.
3. MacLaren G, Barbaro R and Peek G. Expanding extracorporeal membrane oxygenation cannulation strategies in neonatal respiratory failure. *Pediatr Crit Care Med* 2021; 22(8): 756–758.
4. Woods RK. Extracorporeal life support and increased risk of stroke with carotid cannulation: maybe, maybe not. *ASAIO J* 2019; 65: 635.
5. Fraser CDIII, Kovler ML, Guzman W Jr, et al. Pediatric femoral arterial cannulations in extracorporeal membrane oxygenation: a review and strategies for optimization. *ASAIO J* 2019; 65: 636–641.
6. Schad CA, Fallon BP, Monteagudo J, et al. Routine use of distal arterial perfusion in pediatric femoral venoarterial extracorporeal membrane oxygenation. *Artif Organs* 2017; 41(1): 11–16.
7. Shah NR, Spencer BL, Maselli KM, et al. Lower extremity complications in children following femoral cannulation for extracorporeal membrane oxygenation. *Perfusion* 2024; 39(8): 1692–1699.
8. Gander JW, Fisher JC, Reichstein AR, et al. Limb ischemia after common femoral artery cannulation for venoarterial extracorporeal membrane oxygenation: an unresolved problem. *J Pediatr Surg* 2010; 45(11): 2136–2140.
9. Di Gennaro JL, Chan T, Farris RWD, et al. Increased stroke risk in children and young adults on extracorporeal life support with carotid cannulation. *ASAIO J* 2019; 65: 718–724.
10. Harvey C. Cannulation for neonatal and pediatric extracorporeal membrane oxygenation for cardiac support. *Front Pediatr* 2018; 6: 17.
11. Polito A, Barrett CS, Wypij D, et al. Neurologic complications in neonates supported with extracorporeal membrane oxygenation: an analysis of ELSO registry data. *Intensive Care Med* 2013; 39: 1594–1601.
12. Johnson K, Jarboe MD, Mychaliska GB, et al. Is there a best approach for extracorporeal life support cannulation: a review of the extracorporeal life support organization. *J Pediatr Surg* 2018; 53: 1301–1304.
13. Extracorporeal Life Support Organization (ELSO). *ECMO registry*. ELSO, 2010. https://www.elso.org/registry/elsoregistry-basedpublications.aspx (accessed 12 April 2025).
14. Teele SA, Salvin JW, Barrett CS, et al. The association of carotid artery cannulation and neurologic injury in pediatric patients supported with venoarterial extracorporeal membrane oxygenation. *Pediatr Crit Care Med* 2014; 15: 355–361.
15. Rollins MD, Hubbard A, Zabrocki L, et al. Extracorporeal membrane oxygenation cannulation trends for pediatric respiratory failure and central nervous system injury. *J Pediatr Surg* 2012; 47: 68–75.
16. Garcia AV, Etchill EW, Bembea MM, et al. Pediatric arterial femoral cannulations for extracorporeal membrane oxygenation: does size really matter? *J Pediatr Surg* 2021; 56: 1643–1646.
17. Kurkluoglu M, Hynes CF, Alfares FA, et al. Choice of peripheral venoarterial extra-corporeal membrane oxygenation cannulation site in patients above 15 kilograms. *J Card Surg* 2015; 30: 461–465.
18. Buyukgoz C, Sandhu H, Shah S, et al. Strategies and techniques for percutaneous veno-arterial ECMO cannulation and decannulation in children. *Cathet Cardiovasc Interv* 2023; 101(6): 1088–1097.

19. Garcia AV, Jeyaraju M, Ladd MR, et al. Survey of the American pediatric surgical association on cannulation practices in pediatric ECMO. *J Pediatr Surg* 2018; 53: 1843–1848.
20. Short BL, Walker LK and Traystman RJ. Impaired cerebral autoregulation in the newborn lamb during recovery from severe, prolonged hypoxia, combined with carotid artery and jugular vein ligation. *Crit Care Med* 1994; 22: 1262–1268.
21. Short BL, Bender K, Walker LK, et al. The cerebrovascular response to prolonged hypoxia with carotid artery and jugular vein ligation in the newborn lamb. *J Pediatr Surg* 1994; 29: 887–891.
22. Cengiz P, Seidel K, Rycus PT, et al. Central nervous system complications during pediatric extracorporeal life support: incidence and risk factors. *Crit Care Med* 2005; 33: 2817–2824.
23. Pisano DV, Ortoleva JP and Wieruszewski PM. Short-term neurologic complications in patients undergoing extracorporeal membrane oxygenation support: a review on pathophysiology, incidence, risk factors, and outcomes. *Pulm Ther* 2024; 10: 267–278.
24. Carpenter JL, Baker M, Sperberg K, et al. Common carotid artery imaging after vessel sparing decannulation from extracorporeal membrane oxygenation (ECMO) support. *J Pediatr Surg* 2021; 17: 54.
25. Lohrer RM, Bejar RF, Simko AJ, et al. Internal carotid artery blood flow velocities before, during, and after extracorporeal membrane oxygenation. *Am J Dis Child* 1992; 146: 201–207.
26. Yu SH, Mao DH, Ju R, et al. ECMO in neonates: the association between cerebral hemodynamics with neurological function. *Front Pediatr* 2022; 10: 908861.
27. Iqbal S. A comprehensive study of the anatomical variations of the circle of willis in adult human brains. *J Clin Diagn Res* 2013; 7(11): 2423–2427.
28. Aboul-Nour H, Jumah A, Abdulla H, et al. Neurological monitoring in ECMO patients: current state of practice, challenges and lessons. *Acta Neurol Belg* 2023; 123: 341–350.
29. Sellei R, Wollnitz J, Reinhardt N, et al. Non-invasive measurement of muscle compartment elasticity in lower limbs to determine acute compartment syndrome: clinical results with pressure related ultrasound. *Injury* 2020; 51: 301–306.
30. Ahluwalia A, Tiwari K and Somashaker N. Acute compartment syndrome in the limb. *Br J Hosp Med* 2020; 81: 1–6.
31. Bonicolini E, Martucci G, Simons J, et al. Limb ischemia in peripheral veno-arterial extracorporeal membrane oxygenation: a narrative review of incidence, prevention, monitoring, and treatment. *Crit Care* 2019; 23: 266.
32. Lyaker MR, Tulman DB, Dimitrova GT, et al. Arterial embolism. *Int J Crit Illn Inj Sci* 2013; 3: 77–87.
33. Blakeslee-Carter J, Shao C, LaGrone R, et al. Vascular complications based on mode of extracorporeal membrane oxygenation. *J Vasc Surg* 2022; 75: 2037–2046.e2.
34. De Somer F. Critical incidents during cardiopulmonary bypass. In: Vives M and Hernandez A (eds). *Cardiac Anesthesia and Postoperative Care in the 21st Century*. Springer, 2022, pp. 123–135.
35. Haddad P, Chasin C, Xu J, et al. Single-center surgical site infection rate after peripheral ECMO decannulation and surgical repair. *Ther Adv Infect Dis* 2022; 9: 20499361221132148.
36. Son AY, Khanh LN, Joung HS, et al. Limb ischemia and bleeding in patients requiring venoarterial extracorporeal membrane oxygenation. *J Vasc Surg* 2021; 73: 593–600.
37. Jayakumar I. Cannulation in ECMO. *J Ped Crit Care* 2017; 4: 48–53.
38. Jia D, Yang IX, Ling RR, et al. Vascular complications of extracorporeal membrane oxygenation: a systematic review and meta-regression analysis. *Crit Care Med* 2020; 48: e1269–e1277.
39. Huang SC, Yu HY, Ko WJ, et al. Pressure criterion for placement of distal perfusion catheter to prevent limb ischemia during adult extracorporeal life support. *J Thorac Cardiovasc Surg* 2004; 128: 776–777.
40. Schachner T, Bonaros N, Bonatti J, et al. Near infrared spectroscopy for controlling the quality of distal leg perfusion in remote access cardiopulmonary bypass. *Eur J Cardio Thorac Surg* 2008; 34: 1253–1254.
41. Dalton HJ, Reeder R, Garcia-Filion P, et al. Factors associated with bleeding and thrombosis in children receiving extracorporeal membrane oxygenation. *Am J Respir Crit Care Med* 2017; 196(6): 762–771.
42. Rintoul NE, McMichael ABV, Bembea MM, et al. Management of bleeding and thrombotic complications during ECMO: the pediatric ECMO anticoagulation collaborative consensus conference. *Pediatr Crit Care Med* 2024; 137(-7 Suppl 1): e66–e77.
43. Hart JP and Davies MG. Vascular complications in extracorporeal membrane oxygenation—A narrative review. *J Clin Med* 2024; 13: 5170.