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Practice patterns in imaging guidance for ECMO cannulation: A survey of the American Pediatric Surgical Association☆

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ABSTRACT

Background: Surgeon-specific variations in pediatric extracorporeal membrane oxygenation (ECMO) cannulation technique are not well characterized. Advances in technology have led to changing techniques with no formal consensus statement for reference.
Methods: A survey was e-mailed to 1301 members of the American Pediatric Surgical Association (APSA). Categorical data was compared with Chi-squared and Kendall's tau-β tests, and multiple column comparisons were performed with the Bonferroni correction.
Results: Response rate was 19%, with 248 pediatric general surgeons responding to the survey. 89.4% of respondents stated that cannulation was typically performed in the ICU. Venoarterial (VA) ECMO cannulation was more often performed open (88.6%) than venovenous (VV) ECMO (42.2%). Surgeons cannulate for VA ECMO and VV ECMO without imaging guidance 44% and 21.5% of the time, respectively. There was no difference in estimated rate of cannula repositioning by cannulation strategy. For venous and arterial cannulation in VA ECMO, surgeons were more likely to use the femoral as opposed to the neck when children were older than 13 years and weighed more than 35 kg regardless of the presence or absence of preexisting femoral arterial or venous access.
Conclusion: Practice patterns for ECMO cannulation are variable among pediatric surgeons. Standardization could reduce the occurrence of unsafe practices and potentially decrease complications and improve patient outcomes.
Level of evidence: Level IV.

Since its first use in the early 1970s [1], extracorporeal membrane oxygenation (ECMO) has become a frequently used modality for infants and children with severe but reversible cardiac or respiratory failure. This support can be delivered through a venoarterial (VA) or a venovenous (VV) configuration. Traditional neck cannulation for VA ECMO requires the placement of separate cannulas in the internal jugular vein and the carotid artery, but concerns about the long-term neurodevelopmental outcomes secondary to carotid ligation after decannulation have compelled physicians to search for alternative cannulation strategies [2,3]. While VA ECMO remains the predominant configuration in neonates and children, VV ECMO has gained in popularity over the last two decades as the incidence of ECMO in isolated respiratory failure has increased [4]. Additionally, with the advent of portable advanced imaging technology, it is now possible to place cannulas with better accuracy and potentially less risk of harm to the patient.

With the changes in strategy and technology associated with peripheral ECMO cannulation, there has certainly been a learning curve for pediatric surgeons. As cannulation becomes a potentially less invasive procedure, imaging guidance increasingly becomes more important. Additionally, deciding when to safely use the carotid or femoral vessels to avoid cerebral or limb ischemia is not always clear. Complications, including poorly positioned cannulas, are not uncommon and can have detrimental effects in an already critically ill patient. Finally, the Extracorporeal Life Support Organization (ELSO) strongly encourages the implementation of hospital-based credentialing systems for ECMO practitioners with recertification intermittently, particularly for those who do not cannulate often [5].

A recent survey of the APSA membership provided insight into differences in patterns of ECMO patient management, with a focus on surgeon experience and both operative and postoperative decision making [6]. In contrast, the purpose of our survey was to examine variation in practice of the cannulation process, especially the use of imaging guidance. Secondarily, we aimed to evaluate self-reported complication rates related to cannulation, and the use of adjuncts, such as cephalic drains and femoral artery reinfusion catheters. Our hypothesis was that there would be significant variability in the use of imaging guidance during cannulation and low reported complication rates. Additionally, we hoped to gather information to

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demonstrate a need for further attempts at reaching a consensus regarding standardized cannulation guidelines.

1. Methods

This protocol detailed in this study was approved as a consent exempt study by the Indiana University School of Medicine Institutional Review Board (IRB #1612506582). The survey was created using the online platform Survey Monkey (San Mateo, CA) and e-mailed to all members of APSA. APSA's guidelines for survey creation were followed carefully [7]. This process included a pilot run, adjustments to the survey as indicated, and eventual approval by the APSA Outcomes and Evidence Based Practice Committee. Once this was completed, the survey was distributed to 1301 APSA members. The complete survey can be found in Appendix A.

Responses were tabulated, and results reported as a percentage of the respondents. For free response values regarding cutoffs for weight and age, a patient was considered an infant if less than 1 year of age or less than 10 kg, a child if aged 1–13 years and 10–35 kg, and a teenager if older than 13 years and/or greater than 35 kg. Any responses that were not clearly within one of these categories were excluded from the analysis of the free response questions (i.e. numbers without units that could be interpreted as either an age or weight cutoff). Categorical data were compared with chi-square analysis and ordinal data with Kendal's Tau-β tests followed by the Bonferroni correction for multiple column comparisons for nonparametric data. Statistical analysis was completed using SPSS Statistics 24 (IBM, Armonk, NY) and GraphPad Prism (GraphPad Software, La Jolla, CA).

Table 1
Demographics of respondents.

	N (%)
What specialty cannulates?	
Pediatric general surgeon	182 (94.8)
Cardiac surgeon	107 (55.7)
Adult general surgeon	7 (3.6)
Intensivist	3 (1.6)
Interventional Radiologist	3 (1.6)
What type of hospital do you practice in?	
Freestanding children's hospital	140 (72.9)
Children's wing in adult hospital	54 (28.1)
Adult hospital	2 (1.0)
Where do you cannulate for VA ECMO?	
Intensive care unit	159 (82.8)
Operating room	47 (24.5)
Interventional radiology	17 (8.9)
Emergency department	6 (3.1)
Where do you cannulate for VV ECMO?	
Intensive care unit	171 (89.1)
Operating room	55 (28.6)
Interventional radiology	25 (13.0)
Emergency department	5 (2.6)
Does your hospital provide additional specific credentialing for ECMO cannulation?	
Yes	20 (10.6)
No	169 (89.4)

2. Results

2.1. Demographics (Table 1)

Of the population queried, 248 members (19.0%) responded to the survey. Completion rate was only 14.7% (191 surgeons), because some started the survey but did not finish it. Only two respondents practiced outside of the United States, and all respondents identified themselves as pediatric general surgeons. Almost three quarters of respondents practiced at freestanding children's hospitals, and most respondents' hospitals did not provide additional credentialing for ECMO cannulations (89.4%). A clear majority (94.8%) reported that pediatric general surgeons cannulated for ECMO at their institution. However, pediatric cardiovascular surgeons were also cannulating at a significant number of institutions as well (55.7%). ECMO cannulation was most commonly performed in the intensive care unit (ICU), but approximately one in four surgeons also cannulated in the operating room regardless of VA or VV configuration.

2.2. Cannulation strategy and imaging guidance

Respondents were most likely to use a venovenous dual lumen (VVDL) cannula in the right internal jugular for VV ECMO, with only 7 respondents (3.6%) routinely using dual-site single lumen cannulation. 28 (14.6%) reported that they used a weight cutoff as a criterion to decide whether a VVDL line was appropriate, and the range provided was 15–20 kg. For VV ECMO, 73 respondents (38%) always performed open cannulation, while 27 (14.1%) preferred exclusively percutaneous, and the remaining 73 (38%) decided based on patient weight and age — typically open for infants and percutaneous for older children, but weight cutoffs varied from 3 kg to 40 kg. Contrarily, 140 respondents (72.9%) perform VA ECMO cannulation in an open technique exclusively.

VV cannulation was more likely than VA to be performed under imaging guidance, with the majority employing echocardiography (26 respondents, 15.1%), fluoroscopy (48, 27.9%), or both (61, 35.5%) during the procedure. Placement verification after cannulation for VV ECMO was most often achieved by a combination of x-ray and echo, while for VA ECMO it was almost equally likely to be by x-ray alone (Table 2).

The two most commonly used VVDL cannulas were the OriGen (Austin, Texas) and Avalon ELITE (Getinge, Sweden) products, and a significant number of pediatric surgeons used both types of catheters in patients of all ages. Forty percent (76 respondents) preferred the OriGen cannula in the neonatal population (Fig. 1A), while only 24 respondents (12.5%) preferred it over the Avalon in older children. Avalon cannulas were more likely than OriGen cannulas to be placed under imaging guidance (82.5% vs. 70.9%). In neonates, specifically, 80% of cannulas were placed with some sort of imaging guidance (echo, fluoroscopy, or both) no matter what type of cannula was used. There was no significant difference in imaging choice by type of cannula ($p = 0.53$ for pediatric and $p = 0.68$ for neonates). In both pediatric and neonatal patients, approximately 20% of respondents who routinely place Avalon bicaval cannulas are doing so using surface landmarks alone (Fig. 1B).

Arterial access for VA ECMO was preferentially obtained at the carotid artery for 138 (72.3%) respondents, while only 3 (1.6%) routinely used the femoral artery. To determine the site of arterial access, 49 (25.6%) respondents reported that they used an age and weight cutoff — 10 respondents (26.3%) would only cannulate the femoral in a teenager (defined as 13 and older), while 23 (60.5%) would do so in a child and only 5 (13%) in an infant. Venous access for VA ECMO followed a similar pattern, with 168 respondents (87.3%) using the jugular routinely, 36 (1.9%) using the femoral vein, and 21 (10.8%) making individual determinations based on weight or age. Decision making for VA ECMO location was not significantly changed by the presence of a preexisting arterial or venous line in the femoral vessels.

Femoral limb arterial reinfusion catheters in femoral VA ECMO were routinely placed by 99 (51.7%) respondents, and 98 (82.4%) of these are antegrade femoral, with the remaining 21 (17.6%) being retrograde posterior tibial. Of note, 92 (48%) respondents reported placing femoral reinfusion catheters via open technique and 87 (69.6%) place them at the time of ECMO cannulation. 28 (22.4%) respondents place these catheters less than 6 h after ECMO cannulation, and the remaining 10 (8.0%) usually wait more than 6 h.

Table 2
Imaging guidance during and after cannulation.

	Imaging Guidance During Cannulation, *N* (%)				Placement Verification, *N* (%)		
	None	Fluoro/x-ray	Echo	Both	X-ray	Echo	Both
VV ECMO	37 (21.5)	48 (27.9)	26 (15.1)	61 (35.5)	34 (19.7)	7 (4.0)	132 (76.3)
VA ECMO	70 (44.0)	40 (25.2)	9 (5.7)	40 (25.2)	69 (43.7)	4 (2.5)	85 (53.8)

Finally, additional cephalic drainage catheters were routinely placed during VV ECMO by 23 (13.2%) respondents, while 140 (80.5%) never placed them, and the remaining 11 (6.3%) placed them in small infants only. For VA ECMO, these numbers were similar at 20 (12.6%), 135 (84.9%), and 4 (2.5%) respectively.

2.3. Complications related to ECMO cannulation

For either VV or VA ECMO, 42.8 (22.3%) respondents self-reported cannulation-related complications less than 1% of the time, while 130 (67.9%) estimated somewhere between 1% and 10%. Two surgeons (1.1%) self-reported cannulation complication rates greater than 50%. Injury to the heart or great vessels occurred less than 1% of the time for 155 (80.7%) respondents, with 30 (15.6%) reporting a rate of 1%–10%. Major cannula site bleeding occurred less than 10% of the time for 173 (90.2%) respondents. The availability of hospital-provided cannulation credentialing did not have any significant effect on self-reported complication rates.

For both VV and VA ECMO, there was no difference in estimated cannulation complication rates (Fig. 2A) or required cannula repositioning (Fig. 2B) when stratified by type of imaging guidance for placement. A nonsignificant increase in complication rates was noted in those who use both echo and fluoroscopy, with 68.4% and 60.0% of these surgeons reporting greater than 1% cannulation-specific complication rates in VV and VA ECMO, respectively. In contrast, only 62.1% and 52.9% of those who used surface landmarks alone to guide placement reported complications more than 1% of the time.

Specifically, for VV ECMO, 42.6% of those who used both echo and fluoroscopy reported a need to reposition the catheter more than 10% of the time, with 3.3% of this group reporting a rate of more than 50%. Of the group who used surface landmarks alone, only 21.6% reported repositioning more often than 10% of the time, but 2.7% of respondents described a personal rate of more than 50%. For VA ECMO these rates were much lower, with 17.5% of those using both echo and fluoroscopy and only 7.1% of respondents using no imaging needing to reposition more than 10% of the time.

3. Discussion

The results of this survey of APSA surgeons provide insight into the considerable variability in cannulation strategy for ECMO. Unfortunately, there is very little literature available regarding practice standardization when it comes to ECMO cannulation strategies. Additionally, it demonstrates routine deviations in practice from the literature that is available. These results highlight the importance of consensus papers and collaboration among ECMO centers.

While the demographics of the study population were homogeneous, the strategies utilized in both VV and VA ECMO cannulation were not consistent across respondents. While this could be indicative of an inability of the survey to obtain more granular data between respondents regarding characteristics of their practices, it should be

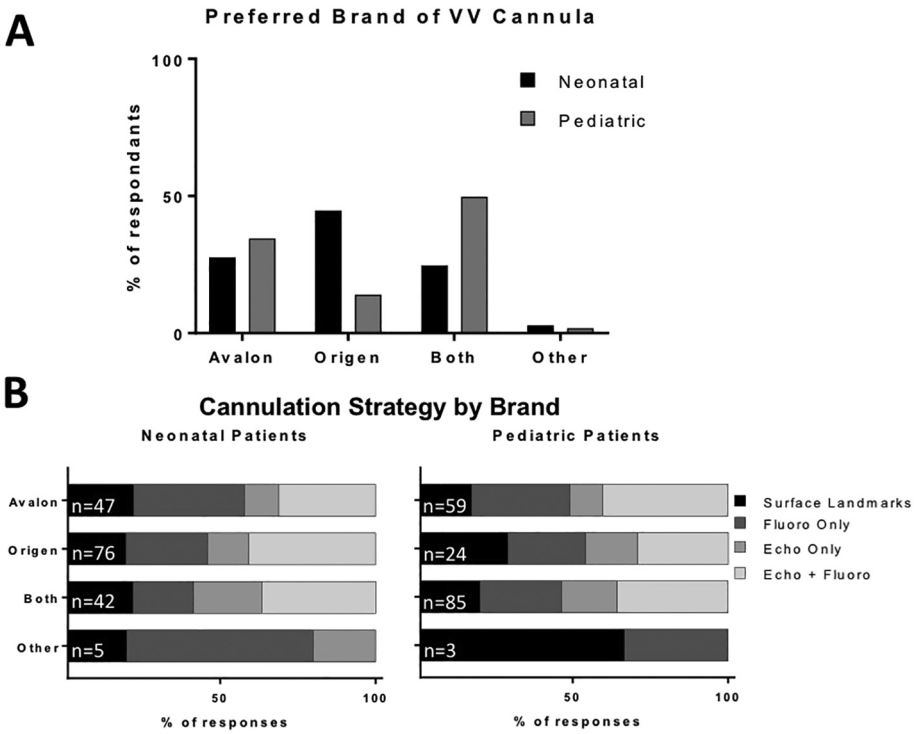

Fig. 1. (A) Respondents were more likely to use the Origin brand cannulae in neonates than in older children. (B) Some respondents who typically use Avalon cannulae still report placement of these without use of imaging guidance, which is not a recommended practice.

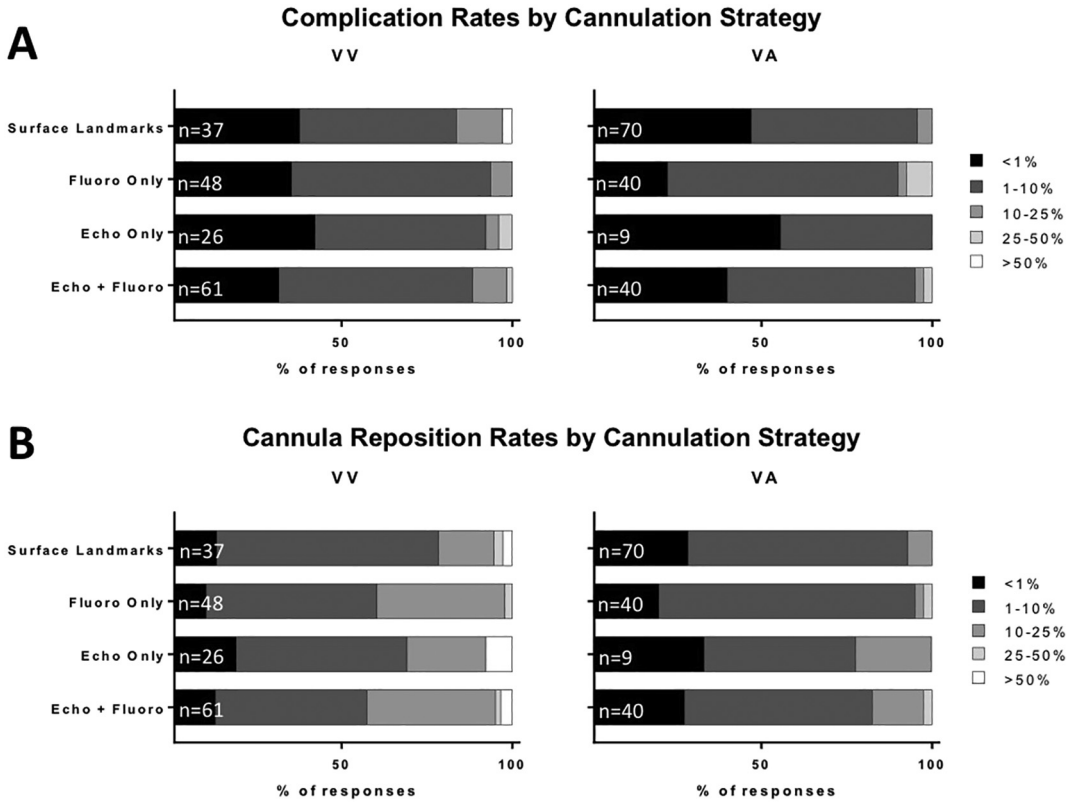

Fig. 2. (A) There was no significant difference in self-reported complication rates based on cannulation imaging-guidance strategy for either VV or VA ECMO cannulation. (B) There was no significant difference in need for cannula repositioning based on cannulation imaging-guidance strategy for either VV or VA ECMO.

considered that the variability is because of to lack of clear consensus on this topic. At this point, it is not surprising that most of the hospitals were not providing a special certification for practitioners who are cannulating for ECMO. Credentialing and continuing education in ECMO were recently proposed by ELSO as important components of qualified ECMO centers. Current ELSO recommendations include an initial certification followed by enrollment in continuing education for any clinician who has not performed an ECMO cannulation within the past 3 months [5]. This type of program would likely be helpful in standardizing care, despite the lack of a difference in our data in reported complication rates among those with and without this certification.

While VV ECMO was traditionally performed with two separate cannulas in the jugular and femoral veins, it is increasingly performed with a single VVDL cannula. Newer cannulas have improved the functional success of single cannula VV ECMO by separating the inlet for venous return from the outlet for oxygenated blood by some distance, thus reducing the amount of recirculation. The OriGen cannula simply separates these orifices by a few centimeters [8], while the Avalon ELITE device is bicaval, with the venous return coming from both the superior and inferior venae cavae, while oxygenated blood is delivered directly to the tricuspid valve through the right atrium [9]. With these new advances in technology, cannulation strategies have changed as well, with many VV ECMO cannulations performed percutaneously and on smaller patients than previously possible [10]. This shift is supported by the data at this time which suggest that percutaneous dual lumen VV ECMO is safe even in neonates when appropriate for the clinical situation [11–13].

As expected, VVDL cannulas were a popular choice for VV ECMO, with a majority using them for most patients. Multiple studies have demonstrated the safety and efficacy of these cannulas, particularly the bicaval Avalon product [9,11]. However, this wire-reinforced cannula is designed to be inserted under imaging guidance to avoid injury to the heart or venae cavae [14,15]. Interestingly, almost 20% of the respondents who indicated that they preferred to use Avalon cannulas for neonates or pediatric patients also reported that they use surface landmarks alone to cannulate for VV ECMO without imaging guidance. Standard of care as discussed in the literature is the use of fluoroscopy [16], transthoracic echocardiogram, and/or transesophageal echocardiography [13,15] to aid in the safe placement of these cannulas. At the minimum, a series of chest x-rays can be used without a fluoroscopy-compatible bed to confirm wire placement before passing the cannula. In placing this cannula, the wire position is extremely important — it is not enough to see the tip in the inferior vena cava, but one must be able to visualize the entire length of the wire to ensure that there are no loops or kinks, which could lead to atrial perforation.

ELSO's published guidelines currently recommend echocardiographic guidance during placement of these cannulas [17]. In light of these recommendations and our survey responses, it appears that further education and consensus on ECMO cannulation practice would likely benefit the surgeons who continue to perform suboptimal cannulation techniques for these VVDL cannulas. While our data did not demonstrate a difference in complication rates between these groups, it is possible that this is because of response bias, i.e. those surgeons who have worse outcomes are less likely to respond to the survey. Of note, vascular access for percutaneous cannulation is typically performed under ultrasound guidance, which is widely accepted to be the safest option [18]. This survey did not specifically address percutaneous access technique but was focused on final positioning of cannulae.

For children who require VA ECMO, the care team must quickly make a decision between carotid and femoral arterial cannulation. In the adult realm, ligation of the carotid may be avoided by arterial cannulation of the common femoral artery in most cases. However, in small children and infants, vessel size can be prohibitive at this location, and limb ischemia may be an unintended sequela [19]. With the wide

range of patients and pathologies and ever improving cannula technologies, there is no consensus or set of standardized recommendations about when to cannulate the groin versus the neck and what imaging strategies to employ for VA ECMO cannulation.

Interestingly, despite concerns that carotid artery ligation leads to adverse neurologic sequelae, a majority of pediatric surgeons continue to routinely cannulate the carotid artery [3,20]. This practice is supported by some literature finding that after correcting for other patient factors, there is no difference in neurologic outcomes in children after carotid ligation for ECMO [21]. Some surgeons do repair the carotid artery after decannulation [22], but this practice was outside the scope of this survey. Alternatively, when the femoral artery is used, the sequela of limb ischemia is certainly significant, and the data are not yet conclusive [19]. At this time practice patterns remain largely center-specific. While the small size of a neonatal femoral artery may limit its use, femoral arterial cannulation in older children may be considered with a limb reinfusion catheter placed at the time of cannulation [23]. Additionally, while jugular cephalic drains theoretically improve circulation to the cerebral vasculature and limit the risk of intraventricular bleed from sudden intracranial hypertension, these are used intermittently. Limited studies demonstrate some benefit in reducing intracranial hemorrhage [24,25], but others did not demonstrate a significant difference [26].

Cannulation for both VA and VV ECMO has the potential for significant technical complications. Injury to the heart or great vessels and major cannulation site bleeding are the most concerning, and in our study, major complications were reported more frequently than we expected. Based on current literature, the design of the Avalon VVDL cannula introduces a real risk of cardiac perforation, estimated at about 4%–15% of children in most studies [15,27,28]. Even when placed under echo guidance, one series of 25 patients had 2 perforations reported [29]. ELSO guidelines and current literature recommend echo or fluoroscopy guidance when placing these cannulas [15,17].

The self-reported rates of minor complications including cannula malpositioning were surprising as well. Those who report using two forms of imaging guidance (echo and fluoroscopy) actually had higher reported rates of complications and cannula repositioning for both VV and VA ECMO. The most surprising finding was the few respondents who reported a greater than 50% chance of cannula malposition even with both echo and fluoroscopy during cannulation for VV ECMO. It is possible that the surgeons who are cannulating without imaging guidance may not be aware of subtle problems with cannula position and therefore do not know that they require adjustment. Alternatively, those who use echo may be making position adjustments that are clinically insignificant. One other option is that the surgeons who learned to cannulate prior to the widespread availability of bedside imaging may not be using it owing to lack of confidence with the technology, which highlights the importance of continuing education. Whatever the reason, these results were surprising, as we expected the use of fluoroscopy in conjunction with echo to significantly improve surgeon confidence, increase accuracy, and decrease complication rates in cannula positioning.

In neonatal and pediatric ECMO, recent literature demonstrated that the use of echo use during cannulation did not significantly reduce the risk of needing to reposition the cannula. This is in line with our survey results, but was surprising, and suggests that echo may be most useful in difficult cannulations as opposed to when used routinely [13]. A recent paper in the adult critical care literature describing the technique of inserting a VVDL cannula using echocardiography serves as a helpful guide and may encourage some surgeons to try this strategy [30].

There are several limitations of this study that are inherent to the nature of surveys. The low response rate may introduce selection bias; however, this is impossible to determine. Unfortunately, our response rate was slightly lower than average for other APSA surveys [6,31], despite two e-mail reminders. Additionally, some of the later questions in the survey received fewer responses, which may represent the participants' unfamiliarity with the topics or simply reduced interest over time. Finally, self-reported complication rates are likely inaccurate and should be interpreted with caution.

4. Conclusions

Among APSA surgeons, there is a wide variation in ECMO cannulation practice patterns. Specifically, use of imaging during cannulation is not at all standardized across this population, with some surgeons placing the new cannulas using unsafe methods that are opposed to expert recommendations, particularly in the case of VVDL cannulas. Additional studies would be helpful to further evaluate current techniques and protocols in attempts to understand and prevent technical complications associated with the procedure. The ultimate goal should be to create a consensus recommendation to allow pediatric surgeons to provide better, safer care to these critically ill patients.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpedsurg.2019.11.010.

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