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Friend or Foe? Venoarterial ECMO via Carotid Artery "Jump Graft": A Case Series

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Abstract: Extracorporeal life support is used in adult and pediatric patients for refractory cardiac and respiratory failure. The great arteries and veins of the neck and groin are often used for cannulation to extracorporeal membrane oxygenation (ECMO). Newer cannulation techniques use the subclavian or axillary arteries, in addition to synthetic grafts anastomosed in end-to-side fashion, from which the cannula is positioned. These newer techniques can prevent need for ligation and sacrifice of important major vessels that is often undertaken in "traditional" direct surgical cannulation strategies. To our knowledge this graft technique has not been performed in pediatric ECMO patients. We describe a case series of nine patients from 2012 to 2017 supported with venoarterial (V-A) ECMO utilizing a synthetic Gore-Tex® "jump graft" sewn in an end-to-side fashion to the right carotid artery, for the arterial cannula insertion. Each patient's hospital course was reviewed with particular consideration given to disease process, site of cannulation, neurologic examination abnormalities noted during ECMO, computed tomography (CT) or magnetic resonance imaging (MRI) evidence of intracranial hemorrhage, and outcomes. Eight of nine patients were successfully cannulated utilizing this technique without neurologic complication. One suffered catastrophic intracerebral hemorrhage. This series is limited by small sample size and single center experience. Further work is needed to determine the advantages and disadvantages of utilizing a synthetic graft in pediatric V-A ECMO. **Keywords**: extracorporeal membrane oxygenation, ECMO, pediatrics, critical care, synthetic graft. *J Extra Corpor Technol. 2022;54:67–72*

Extracorporeal life support (ECLS) continues to evolve and play an important role in the intensive care management of cardiac and respiratory failure in adult and pediatric patients who fail conventional therapies (1). In patients requiring venoarterial extracorporeal membrane oxygenation (V-A ECMO) support, arterial sites for cannulation most often include the carotid or femoral arteries, with newer techniques utilizing the subclavian or axillary arteries (2,3). The use of distal perfusion cannulas or placing a side graft in the target artery came about from the observation of interference of distal flow to the cannulated limb leading to ischemia (4). There have not been reports of outcomes or complications associated with the use of axillary or carotid artery synthetic grafts in pediatric V-A ECMO patients. In adults, newer techniques using an axillary artery side graft note advantages including lack of atherosclerosis and potentially minimizing embolization, guaranteed forward flow into the aorta, and preferential delivery of oxygenated blood to the heart and brain (3).

Site of cannulation is often a multidisciplinary discussion between the critical care team and the cannulating surgeon, taking into consideration the age, size, and pathology of the patient. Often, direct surgical cannulation of large central veins and arteries requires either ligation and sacrifice or vascular reconstruction once the patient is able to be decannulated from ECMO. This can lead to significant morbidity for the patient, such as thrombosis, and longer surgical decannulation times. This series reviews the first ECMO cannulations performed utilizing carotid artery "jump grafts," synthetic tubing used to connect an ECMO cannula via anastomosis to the side of an artery, in pediatric patients at our institution (Table 1). These newer techniques can prevent need for ligation and sacrifice of important

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Table 1. Single center experience: use of carotid arterial graft in pediatric VA-ECMO cannulation.

Age in years, Sex	Weight in Kilogram	Diagnoses and Complications	Time on ECMO in Hours	Head CT	Neurologic Sequela from ECMO	Carotid Artery Repair	Outcome
19, male	75	SVC syndrome, closure retrograde	147	Normal	None	Primary closure	Survival to discharge
15, female	75	Flu, significant bleeding	609	Normal	None	n/a	Death, withdrawal of support
19, male	73	Sepsis, CPR prior to ECMO	170	None	None	n/a	Death, withdrawal of support
7, male	25	Sepsis, ECPR	21	Normal	None	n/a	Death
3, female	16	Parvovirus myocarditis	161	MRI post ECMO	Petechial hemorrhage	Clip and suture ligation of graft	Survival to discharge
13, female	48	Hemolytic Uremic Syndrome	267	Prior to ECMO	None	n/a	Death
15, female	77	MRSA Necrotizing Pneumonia	387	None	None	Chimney graft ligated	Survival to discharge
13, female	44	B cell ALL Legionella	57	Abnormal	Large hemorrhage	n/a	Death, withdrawal of support
18, female	85	Heart failure of unknown etiology	65	None	None	Inter-facility transport on ECMO	Survival to transfer

ALL, acute lymphoblastic leukemia CPR, cardiopulmonary resuscitation; CT, computed tomography; ECMO, extracorporeal membrane oxygenation; E-CPR, extracorporeal cardiopulmonary resuscitation; MRI, magnetic resonance imaging; MRSA, methicillin-resistant *Staphylococcus aureus*; SVC, superior vena cava.

major vessels that is often undertaken in "traditional" direct surgical cannulation strategies.

Institutional review board (IRB) approval was sought and this review of our case series was deemed not human subject research, and was exempt.

At our institution, we maintain and assemble our own ECMO circuit setup. We use the Maquet Rotaflow® RF-32 (Getinge, Sweden) and Sorin Revolution® (Mirandola, Italy) (LivaNova, London, England) centrifugal blood pumps, with either the adult or pediatric Maquet Quadrox iD® (Getinge) or Sorin EOS (LivaNova) oxygenators. Our tubing circuitry includes a stopcock bridge between the arterial and venous limbs, a sterile loop, a medication shunt with manifold, and shunting post-oxygenator to the venous limb. For continuous monitoring of patients' extracorporeal flow, mixed-venous oxygen saturation, hematocrit, and post-membrane oxygen saturation, we use the Spectrum M3 (Spectrum) monitor with the Stockert SIII or Sorin SV (LivaNova) base to provide continuous pressure monitoring and battery backup. Both bases are used in conjunction with the Stockert Centrifugal Pump Console and Electronic Remote Clamp to provide post-oxygenator air protection. For thermoregulation, we use the CardioQuip™ (CardioQuip, College Station, TX) MCH-1000(m) Modular Cooler-Heater®.

DESCRIPTION

Case 1

A 19-year-old 72-kg male presented with two months' history of emesis and weight loss. Pertinent past medical history included familial hypertrophic cardiomyopathy and Wolff–Parkinson–White syndrome. He required ECMO cannulation due to progressive heart failure with end-diastolic dysfunction (EDP = 20 mmHg), pulmonary hypertension, and respiratory failure. His right internal jugular vein (RIJ) was cannulated using a 27-French Avalon® dual-lumen bicaval cannula. The following day, he underwent anastomosis of an 8-mm Gore-Tex® graft onto his right common carotid artery (RCCA) for arterial cannulation (22-Fr EOPA® [Medtronic, Minneapolis, MN]) conversion of venovenous (V-V) to V-A ECMO support. His course was complicated by renal failure requiring continuous renal replacement therapy (CRRT) via the ECMO circuit, superior vena cava (SVC) syndrome requiring placement of a retrograde SVC cannula, and atrial septostomy. He developed anisocoria; however, a head CT did not demonstrate any intracerebral hemorrhage. He had a primary repair of the RIJ and ligation and primary closure of the RCCA Gore-Tex® graft. He survived to discharge.

Case 2

A 15-year-old 75-kg female presented with cough, emesis, and diarrhea. She was diagnosed with influenza and she was started on oseltamivir. Her past medical history was notable for depression and she resided at a psychiatric facility. She required cannulation to ECMO for severe acute respiratory distress syndrome (ARDS) due to influenza, and pulmonary hemorrhage. She was cannulated via the RIJ using a 27-Fr Avalon® dual-lumen bicaval cannula with the addition of an RIJ cephalad venous cannula. She had a 20-Fr arterial cannula (EOPA® [Medtronic]) placed via an 8-mm Gore-Tex® graft placed onto her RCCA which later required replacement with a 24-Fr cannula. She required multiple re-explorations for the control of surgical-site bleeding. Her course was complicated by fluid overload and renal failure requiring CRRT, loss of myocardial function and requirement of a blade and balloon septostomy (Lap = 30 mmHg). She later required median sternotomy secondary to bleeding and bronchopleural fistula and hemothorax after failed Factor VII therapy. She suffered from both Methicillin-resistant *Staphylococcus aureus* (MRSA) and *Escherichia coli* sepsis. She developed thrombocytopenia-associated multi-organ failure (TAMOF) and received therapeutic plasmapheresis. From a neurologic standpoint she had intermittent anisocoria; however, multiple head CT scans were negative for intracranial hemorrhage. She died secondary to persistent bleeding.

Case 3

A 19-year-old 73.3-kg male presented with muscle and right hip pain. He developed profound septic shock and capillary leak secondary to Group A *Streptococcus* and underwent cervical cannulation to V-A ECMO. Before ECMO, he underwent exploratory laparoscopy with peritoneal drain placement for abdominal compartment syndrome, pericardiocentesis for pericardial effusion causing tamponade physiology, and placement of bilateral chest tubes for pleural effusions. He suffered cardiac arrest before ECMO cannulation. Two days after arrest, he underwent placement of a 10-mm Gore-Tex® graft onto the RCCA for arterial antegrade and retrograde perfusion via a 24-Fr cannula. A 24-Fr RIJ cannula was placed along with an 18-Fr distal jugular vein drainage cannula (Thin-Flex Venous [Edwards Lifesciences, Irvine, CA]). The course was complicated by inadequate venous return necessitating a 24-Fr saphenous venous cannula as well as an 18-Fr distal left common femoral vein antegrade and retrograde cannula. He had recovery of cardiopulmonary function yet persistent renal failure requiring CRRT. The RCCA cannula was removed and clip and suture ligation of the Gore-Tex® graft was performed. There was primary repair of the RIJ and left femoral vein. Electroencephalography (EEG) while on ECMO did not demonstrate any epileptiform activity. No cranial imaging was done before decannulation. Due to continued deterioration, goals of his care were redirected toward comfort measures, and he died 7 days later.

Case 4

A 7-year-old 25.8-kg male presented with fever and lethargy. He required ECMO cannulation for septic shock due to Group B *Streptococcus* requiring multiple episodes of cardiopulmonary resuscitation. He required extracorporeal cardiopulmonary resuscitation (E-CPR) before achieving return of a perfusing rhythm. He underwent placement of a 6-mm Gore-Tex® graft onto the RCCA via an 18-Fr cannula (EOPA® [Medtronic]), with a 22-Fr RIJ cannula and an additional 14-Fr distal jugular vein cephalad drainage cannula. His course was complicated by inadequate venous return secondary to massive volume overload and abdominal compartment syndrome. Cannula repositioning was unsuccessful. Despite ongoing care and resuscitation, his metabolic acidosis could not be corrected. He died the next day.

Case 5

A 3-year-old 16.4-kg female presented with myocarditis secondary to Parvovirus and required cervical ECMO cannulation. She underwent placement of an RCCA 4-mm Gore-Tex® graft via a 14-Fr arterial cannula (DLP® [Medtronic]), as well as RIJ 16-Fr proximal (Edwards Lifesciences) and 12-Fr distal cannula (Bio-Medicus™ [Medtronic]). She required transport to the heart catheterization lab for blade and balloon septostomy (mLAp = 33 mmHg). Her ECMO course was complicated by nasopharyngeal bleeding secondary to mucosal erosion by the endotracheal tube, which required multiple ENT interventions to obtain hemostasis. There was recovery of myocardial function and ECMO was discontinued after an extended trial-off. Her vessel repair included clip ligation of the Gore-Tex® graft and primary repair of the RIJ. Ten days later, she developed alterations in mental status. Brain magnetic resonance imaging (MRI) demonstrated subacute infarcts in the right posterior frontal lobe and right cerebellar hemisphere, without acute infarct. Punctate hemorrhages were seen within the subacute areas of infarction in addition to an epidural hematoma measuring $1.8 \times 2.3 \times 1.2$ cm, abutting the right sigmoid plate and causing compression of the right sigmoid sinus. MRA was normal.

Case 6

A 13-year-old 48.6-kg female presented with complement mediated hemolytic uremic syndrome with

associated severe cardiomyopathy. She progressed to worsening shock and myocardial failure necessitating ECMO support. Initially, the right femoral artery and vein were cannulated, however, adequate flows could not be obtained because of high arterial resistance. The RCCA was then cannulating using an 18-Fr cannula (EOPA® [Medtronic]), and a 6-mm Gore-Tex® graft as well as a 25-Fr RIJ cannula (Bio-Medicus™ (Medtronic). The femoral cannulation site was closed with primary repair and clip ligation of the graft used at the arterial site. Six days later, she developed abdominal compartment syndrome with colonic perforation and underwent exploratory laparotomy. Because of continued refractory bleeding despite holding heparin infusion, her family elected to redirect care to comfort measures and she was decannulated. She died immediately.

Case 7

A 15-year-old 77-kg female presented with cough. She progressed to refractory hypoxemia and respiratory failure secondary to necrotizing pneumonia due to *Staphylococcus*. She was initially cannulated to V-V ECMO via the RIJ using a 23-Fr Avalon® dual-lumen bicaval cannula. Due to ongoing air-leak syndrome with refractory bronchopleural fistula, lung isolation was attempted with a 7-Fr bronchial blocker applied to the left mainstream bronchus. Two days later, she required conversion to V-A ECMO using an 8-mm Gore-Tex® graft to the right common carotid artery and a 20-Fr arterial cannula (EOPA® [Medtronic]) for 7 days, after which her arterial cannula was removed and her graft was ligated. One week later, she was successfully decannulated. Primary repair of RIJ was performed.

Case 8

A 13-year-old 44.6-kg female with pre-B-cell acute lymphoblastic leukemia (pre-B ALL) undergoing delayed intensification therapy with steroids presented to the emergency department with lethargy and confusion. She was admitted to the pediatric intensive care unit due to pneumonia, altered mental status, and hypotension. She had septic shock and multi-organ failure from *Legionella pneumophila*. Serial echocardiograms demonstrated worsening left ventricular systolic function, with left ventricular ejection fraction nadir of 29% by M-mode measurement, and moderately diminished right ventricular function. Her RIJ was cannulated using a 24-Fr venous cannula and her RCCA was cannulated using an 8-mm Gore-Tex® graft and a 20-Fr arterial cannula (EOPA® [Medtronic]) for V-A ECMO. Initial ECMO flow of 2.55 (max 3.5) liters per minute (LPM), cardiac index 1.7–1.8, sweep gas flow rate of 2 LPM, and membrane FiO2 1.

Her ECMO course was complicated by streaming of oxygenated "arterial ECMO blood" to the head, neck, and right arm with significant hyperemia in these regions, but systemic hypoxemia. Notably during this time, her cerebral near-infrared spectroscopy (NIRS) monitor was exceedingly high, in the mid-90%s, with low systemic mixed-venous oxygen saturation and low renal NIRS. She continued to be pancytopenic despite frequent blood product transfusions and granulocyte-colony stimulating factor administration. She developed anisocoria and head CT demonstrated large right parietal intraparenchymal hemorrhage. After consulting with Neurosurgery and discussing with her family, she was clamped off of ECMO and high-frequency oscillatory ventilation was attempted. She quickly decompensated and her family elected to redirect care.

Case 9

A 17-year-old 84.8-kg female presented with abdominal pain and emesis, with subsequent diagnosis of myocarditis. Echocardiogram demonstrated mildly dilated right atrium, moderately dilated left atrium, moderate tricuspid valve regurgitation, moderate mitral valve regurgitation, severely diminished left ventricular systolic function, moderately dilated LV, moderately diminished right ventricular function, with an estimated LVEF of 17%. Initial cannulation to ECMO was attempted through the groin, however, this attempt was aborted and vessels repaired due to the small size of the femoral artery. A 29-Fr venous cannula (Bio-Medicus™ [Medtronic]) was inserted, as well as a 20-Fr arterial cannula (EOPA® [Medtronic]) into the RCCA via an 8-mm Gore-Tex® graft. She underwent balloon atrial septostomy in the heart catheterization lab. Patient was transported on ECMO to another center for heart transplant evaluation.

RESULTS

Of the nine cases reviewed, patients' ages ranged from 5 to 19 years with weights ranging from 16 to 85 kg. Three patients were male and six were female. All patients were successfully surgically cannulated to V-A ECMO utilizing a Gore-Tex® "jump graft "sewn in an end-to-side fashion to the right carotid artery, for the arterial cannula insertion. Patients received cranial imaging if there was a change in neurologic examination during or after the ECMO course. One patient had petechial hemorrhage on MRI after ECMO, but no neurologic sequelae. Four patients survived to discharge or transfer out of the ICU. Four patients died after withdrawal of ECMO support secondary to complications of their underlying condition or due to medical futility.

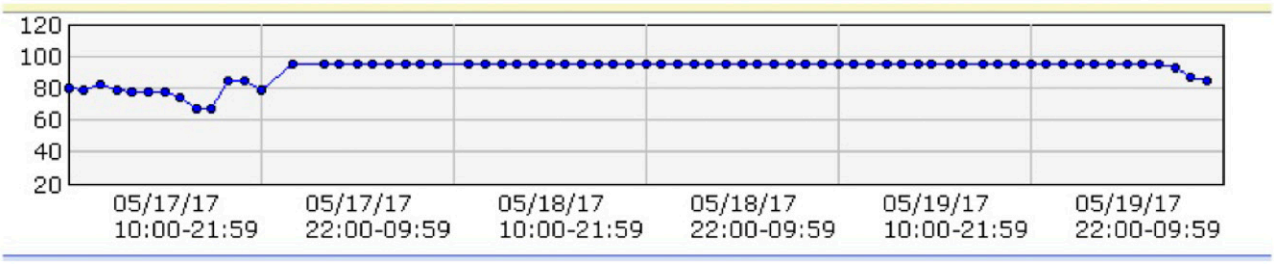

Figure 1. Cerebral near-infrared spectroscopy (NIRS) for Patient 8 with hyperemia to the head and neck who later developed catastrophic intracerebral hemorrhage.

One patient, the 13-year-old female with pre-B-ALL and Legionnaire's disease, experienced hyperemia with increased flow to the head, neck, and right arm, as evidenced by significantly elevated cerebral NIRS (see Figure 1). Interestingly, her systemic mixed-venous oxygen saturation and renal NIRS were low. Two days after cannulation, she sustained a large right-sided intraparenchymal hemorrhage with sulcal effacement and midline shift with the loss of pupillary and corneal reflexes on examination. This necessitated decannulation from ECMO, after which life-sustaining measures were subsequently withdrawn.

COMMENTS

V-A ECMO provides both cardiac and respiratory support (5). Cannulation is achieved either centrally or peripherally with return of blood via the carotid, axillary, or femoral artery utilizing the Seldinger technique or surgical cut-down (3). Multiple authors cite the use of novel techniques, including subclavian and axillary artery cannulation for V-A ECMO support in adults utilizing a graft placed in an end-to-side fashion as a means to potentially avoid complications associated with traditional cannulation techniques, including sacrifice of the cannulated vessels (3,4,6). Figure 2 illustrates this technique (7). Chikotka and colleagues recently published their experience of adults on V-A ECMO utilizing an internal jugular vein drainage cannula with arterial return cannula inserted into a synthetic graft anastomosed to the axillary or innominate artery (6). This approach facilitated early patient mobilization, as well as reduction in differential oxygenation or the "Harlequin effect" that can be seen in femoral artery cannulation (6).

In a single center experience, Chamogeorgakis, et al. found that of their 308 adult patients supported with ECMO from 2001 to 2011, 81 adult patients cannulated with a side graft sewn to the axillary artery experienced hyperperfusion syndrome to the ipsilateral extremity as

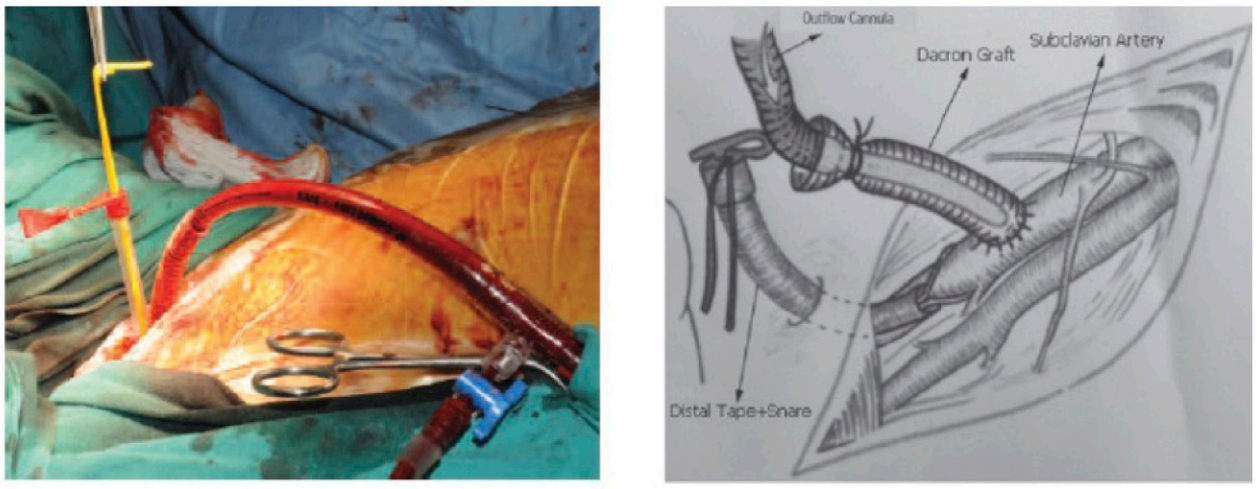

Figure 2. (left) Outflow graft and arterial cannula on subclavian artery and (right) schematic diagram of subclavian artery cannulation as an outflow of extracorporeal membrane oxygenation circuit. Used with permission from Kervan U, Kocabeyoglu S, Sert DE, et al. A novel technique of subclavian artery cannulation for venoarterial extracorporeal membrane oxygenation.

the most common complication ($n = 20$) (3). Of 166 (53.9%) who underwent femoral artery cannulation, lower extremity ischemia and fasciotomy were more frequent complications (3). A retrospective cohort analysis compared complications and outcomes between ultrasound-guided percutaneous cannulation and arterial side-graft techniques in adults who required V-A ECMO for refractory cardiogenic shock (7). There was no significant difference in the rate of limb ischemia; however, cannulation site bleeding and hyperperfusion syndrome were higher in the side-graft group (8).

A retrospective analysis of data from the Extracorporeal Life Support Organization (ELSO) registry found pediatric patients aged 18 years or younger had a statistically significant increased odds of neurologic injury with carotid artery cannulation for V-A ECMO (9). Of the 2,977 pediatric patients supported with V-A ECMO, 611 (21%) had evidence of neurologic injury defined as seizures, infarction, or hemorrhage. This occurrence varied by cannulation site with the carotid artery being most prevalent ($n = 433$, 23% $p = .001$) (9). Neonates had the highest burden of V-A ECMO carotid artery cannulation and neurologic injury. Carotid artery cannulation was found to independently increase odds of neurologic injury (odds ratio 1.4 [95% CI, .84–1.34]) (9).

Prior to our case series, there existed no published description of the use of synthetic grafts sewn onto the carotid artery in pediatric V-A ECMO. Data on outcomes and complications utilizing this technique were therefore unavailable. In this review of the use of carotid arterial grafting in V-A ECMO cannulation at our institution, eight of nine patients were successfully cannulated utilizing this technique without neurologic complication. This surgical ECMO cannulation technique can prevent need for ligation and sacrifice of important major vessels that is often undertaken in "traditional" direct surgical cannulation strategies. Because of its nature of an additional surgical step in the cannulation process, its use may be limited in the timeliness of E-CPR cannulation, however.

Upon reflecting on our patient with complications of streaming and hyperemia to the head, neck, and right arm following the use of a carotid artery "jump graft," along with subsequent catastrophic neurologic sequelae, one must weigh the risk of neurologic complications with preferential high blood flow rates to the unprotected cerebral arterial circulation. Particular care and a high level of suspicion should be applied in these patients to ensure that hyperoxygenated ECMO blood flow is directed toward the body, not solely cephalad.

CONCLUSION

V-A ECMO cannulation utilizing a Gore-Tex® "jump graft "sewn in an end-to-side fashion to the right carotid artery for the arterial cannula insertion is feasible, and can provide benefits to the patient by prevention of carotid artery sacrifice and later carotid arterial repair. However, the risks of this procedure must be considered when this carotid arterial "jump graft" approach is being considered. Further work is needed to better define risk factors for neurologic injury and hemorrhage in pediatric ECMO.

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