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Portable CT Pulmonary Angiogram in an Infant on Veno-Arterial Extracorporeal Membrane Oxygenation in the Pediatric Intensive Care Unit

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Purpose: Computed tomography (CT) has been shown to change management in children on extracorporeal membrane oxygenation (ECMO). Although techniques have been described to transport these critically ill patients to the CT suite in the radiology department, transport out of the intensive care setting is not without risk, and using portable CT is a practical alternative. However, obtaining a CT pulmonary angiogram (CTPA) in a patient on veno-arterial (VA) ECMO presents unique challenges due to bypass of the cardiopulmonary system, which may lead to suboptimal opacification of the pulmonary arteries.
Methods: We describe a method to obtain a diagnostic CTPA study in an infant on VA ECMO in the intensive care unit using portable CT. Our solution involved temporary withholding ECMO and using the venous cannula to deliver a compact contrast bolus to the right atrium to adequately opacify the pulmonary arteries. Special attention was given to the delivery of the contrast bolus, which was given by hand injection, to ensure it coincided with image acquisition and minimized the time ECMO was withheld.
Results: We were able to successfully obtain a diagnostic CTPA study in an infant on VA ECMO in the intensive care unit using portable CT.
Conclusion: This case demonstrates that in select instances CTPA in infants on VA ECMO can be achieved using a portable CT system.

Introduction

In infants and children with reversible causes of pulmonary or cardiopulmonary failure extracorporeal membrane oxygenation (ECMO) can be lifesaving. However, complications frequently arise both intrinsic to ECMO itself and from the primary disease process. Imaging used to diagnose these complications traditionally has been limited to bedside radiography, sonography, and echocardiography.[1] Although useful, these modalities are limited in their detection and characterization of some types of pathology that are best demonstrated with computed tomography (CT).[2,3] Although protocols have been described for the safe and efficient transfer of patients on ECMO from the pediatric intensive care unit (PICU) to the CT suite in the radiology department, these protocols are complicated to implement and require that a critically ill patient leave the PICU.[4,5] This makes portable CT desirable as a practical alternative. Here we describe our technique for obtaining a diagnostic CT pulmonary angiogram (CTPA) in an infant in the PICU using a portable CT system. Our case was uniquely challenging because we needed to obtain a CTPA in a patient on veno-arterial (VA) ECMO. VA ECMO bypasses the cardiopulmonary circulation, effectively acting as a right to left shunt leading to suboptimal opacification of the pulmonary arteries when using normal imaging protocols.[6-9] We addressed this problem by administering contrast through the venous cannula while ECMO flow to the patient was temporarily clamped.

Description

Case

A 6-week-old male was placed on ECMO for acute respiratory distress syndrome accompanied by methicillin-sensitive *Staphylococcus aureus* bacteremia and septic shock. He initially presented with an 8 day history of tachypnea and fever up to 101.5°F and was intubated for worsening respiratory distress secondary to bilateral methicillin-sensitive *S. aureus* pneumonia. Later, he developed recurrent pneumothoraces requiring multiple chest tubes, and by the second week of hospitalization was transferred to our PICU for veno-venous (VV) ECMO due to worsening oxygenation. He was concurrently placed on continuous VV hemofiltration for renal failure. On day 14 of VV ECMO, he developed right heart failure and severe pulmonary hypertension requiring conversion to VA ECMO. Despite conversion to VA ECMO with full

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TABLE
Portable CT specifications

Manufacturer	Neurologica (a subsidiary of Samsung)
Model	CereTom
Bore	32 cm
Scan area	Chest
Scan length	112 mm
Tube voltage	100 kVp
Tube current	3 mA
Dose modulation	No
CTDIvol	5.40 mGy (16 cm phantom)
DLP	60.75 mGy-cm (16 cm phantom)
Pitch	1
Slice collimation	1.25 mm
Slice width	0.625 mm
Contrast	2 mL/kg
Volume	10 mL (diluted to 20 mL with normal saline)
Flow rate	Approximately 2 mL/s (hand injected)
Acquisition type	Helical
Software version	6.02.02

cardiac support, his right heart failure persisted. An echocardiogram demonstrated a dilated right ventricle with suppressed systolic function and right ventricular hypertension. A CTPA was ordered to evaluate for pulmonary emboli.

Equipment and Materials

Portable CT System Neurologica CereTom, software version 6.02.02 (Table).
Omipaque 300, GE Healthcare.
Sorin S3 Roller Head ECMO Pump with Medtronic Circuit
Maquet Quadrox-iD Pediatric Oxygenator
Better Bladder, Circulatory Technology

Technique

Personnel

Support personnel included a radiologist, a pediatric critical care intensivist, a pediatric critical care fellow, a pediatric cardiac intensivist, 2 radiology technologists, 2 ECMO technicians, 2 nurses, and a medical student. Observing radiation safety precautions, only essential personnel remained in the room during image acquisition with appropriate protective equipment.

Monitoring

Patient monitoring included continuous arterial blood pressure, heart rate, and pulse oximetry.

Contrast Preparation

The contrast dose of 10 mL Omnipaque 300 was determined by weight (2 mL/kg) and diluted with 10 mL of normal saline for a total of 20 mL. Another 30 mL syringe of normal saline was prepared as a flush.

Prescan

The patient was positioned in the scanner bore with careful attention to ensure adequate room for support devices, and adequate length of lines and tubes to allow for safe excursion during imaging. Scout images were obtained.

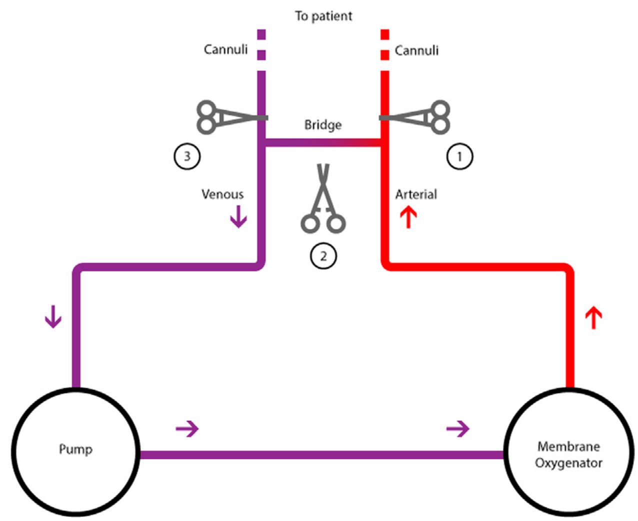

FIG 1. Schematic demonstrating VA ECMO configuration. When ECMO was withheld, the arterial cannula was clamped (1), the bridge was unclamped (2), and then the venous cannula was clamped (3), in that order. Upon resuming ECMO the reverse sequence was performed (3, 2, 1).

ECMO Withheld

The patient's ECMO circuit consisted of a venous drainage cannula in the right atrium and the arterial return cannula in the left common carotid artery. ECMO was withheld by clamping both of the cannulas as per routine protocol for procedures such as circuit changes. The arterial cannula was clamped first, following this the bridge between the cannulas was opened to allow flow through the circuit, and then the venous cannula was clamped (Fig 1).

Image Acquisition

The scan was initiated. Our portable CT system has a 6 second delay between scan initiation and image acquisition. During this delay the contrast bolus was delivered into the venous cannula tubing by hand injection. The position of the contrast bolus in the tubing was then adjusted by hand with saline flush. This was done so that its delivery to the right atrium would coincide with the beginning of image acquisition, after the 6 second delay. At the onset of imaging acquisition the contrast bolus was flushed into to the right atrium over 10 seconds using hand injection technique.

ECMO Resumed

When the right atrium and main pulmonary artery were visualized on the console in real time ECMO was resumed without pausing image acquisition. Image acquisition was allowed to complete.

Outcome

There were no identifiable complications. ECMO was withheld for a total of 37 seconds. During this time the patient's oxygen saturation dropped to a nadir of 60%, but returned to baseline of $>96\%$ once ECMO was resumed. His other biochemical indices remained unchanged prior to and after the procedure (including blood gasses and lactates). The patient tolerated the procedure well despite his otherwise discouraging clinical picture. An adequate CTPA study was obtained. The right heart and pulmonary arteries were adequately opacified, excluding pulmonary emboli.

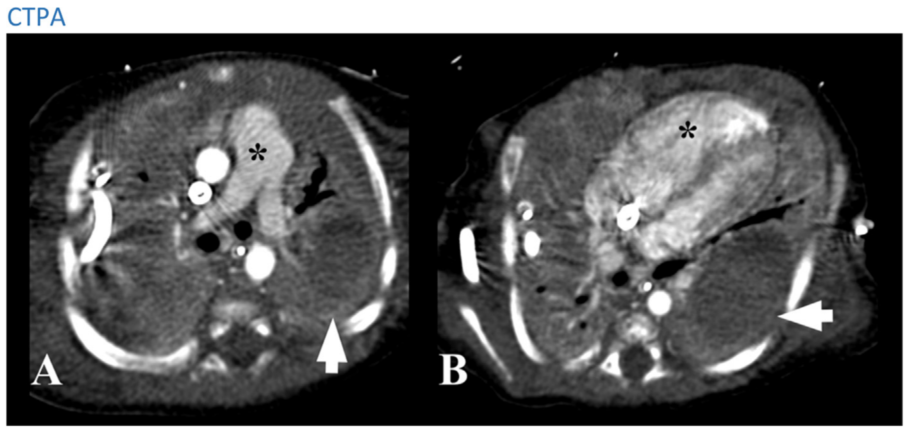

FIG 2. (A) Axial image demonstrates adequate angiographic phase in both the pulmonary arteries HU 326 (*) and the aorta. Higher contrast attenuation in the aorta than in the pulmonary artery was likely the consequence of resuming ECMO prior to completion of the scan, which resulted in some of the contrast bolus being siphoned off via the venous cannula. There was no pulmonary embolus. (B) Oblique 4 chamber view of the heart demonstrates enlargement of the right ventricle (*) consistent with known right heart failure. Multiple debris filled collections in the lung parenchyma are consistent with necrotizing pneumonia (arrows). (Color version of figure is available online.)

However, there were multiple, debris filled, collections in the lungs consistent with necrotizing pneumonia (Fig 2).

Discussion

Background

Although protocols for the safe and effective transport of patients on ECMO have been described, because of inherent transportation related risks we prefer not to have these patients leave the safety of the PICU unless absolutely necessary.[4,5] As an alternative we use a portable CT system. Using a portable CT system to evaluate infants on ECMO comes with a unique set of challenges.

Bore Size

The small bore of our portable CT scanner limits studies obtained on this system to the head and neck in an older child, but in an infant, studies of chest and abdomen can be obtained. Before image acquisition we make sure that there is enough room in the bore for both the patient and support devices. Our system has a bore size of 32 cm, and in this case there was adequate room for all support devices. However, portable CT scanners with a larger bore size of 85 cm are commercially available.

VA ECMO and Vascular Access

VA ECMO bypasses the cardiopulmonary circulation, acting as a right to left shunt. In this patent with right heart failure we were concerned that any contrast delivered to the right atrium would be siphoned off by the venous cannula resulting in suboptimal opacification of the pulmonary arteries. In some reported cases, attempts at CTPA in patients with VA ECMO have resulted in suboptimal contrast within the pulmonary artery system, so reducing ECMO flows, or temporarily withholding ECMO flow has been advocated.[6-9] In our case we elected to temporarily withhold ECMO. This allowed us to avoid the shunting effect of the ECMO circuit and at the same time allow us to use the venous cannula to deliver the contrast bolus. Our patient had a left arm peripheral inserted central catheter, but the small gauge of this vessel would be have been suboptimal for the delivery of a compact contrast bolus required for CTPA. If there had been a right sided central line this could have been used and ECMO flows could have been reduced instead of withheld completely. We diluted the contrast with normal saline in a 50:50 ratio because we theorized that a larger volume would facilitate mixing in the right atrium in this patient with right heart failure.

Contrast Bolus Timing

Unlike the stationary scanner in the CT suite our portable CT system is not equipped with region of interest contrast bolus tracking, and there is a 6 second delay between the initiation of the scan and image acquisition. This presents the problem of ensuring optimal timing of the contrast bolus to adequately opacify the right ventricle and pulmonary arteries. Fortunately, the ECMO cannula tubing is clear and this allowed us to determine the location of the contrast bolus by visualizing the contrast-saline interface. Although both the contrast and saline are clear, the difference in densities creates a visible interface. We adjusted the position of the contrast bolus in real time by hand injection with saline flush to ensure that its delivery to the right atrium would coincide with the beginning of image acquisition.

Image Acquisition

To minimize the time that ECMO was withheld, we did not wait for the completion of image acquisition to resume ECMO. Once the right atrium and pulmonary artery were visualized on the console and shown to have adequate contrast opacification ECMO was immediately resumed. Denser opacification of the aorta compared to the pulmonary arteries on this study may have been due to siphoning off of some of the contrast bolus from the right atrium by ECMO before the scan was complete, or due to slight offset in timing between delivery of the bolus and image acquisition (Fig 2).

Patient Selection

Not every patient is a candidate for reducing or withholding ECMO flow. Patients must be individually evaluated to determine if ECMO can we withheld, and for how long. Even in the patients in who it is feasible, the risk of withholding ECMO and the benefit of imaging must be carefully evaluated. In this case ECMO was withheld for a total of 37 seconds. Although well tolerated in this patient, not all patients are candidates for this technique and patient uniqueness limits generalizability. Careful planning and coordination between the ECMO technician, CT technologist, intensivist, and radiologist is essential to minimize the time that ECMO is reduced/withheld and maximize optimal contrast bolus timing delivery.

Dose

The Computed tomography dose index volume (CTDIvol) for this study was 5.40 mGy using a 16-cm phantom reference. This converts to approximately 2.35 mGy when normalized to a 32-cm phantom.[10] This is comparable to the national average for the 0-2 age group which is approximately 2 mGy.[11] The dose may decrease as portable CT technology improves.

Outcome

The images demonstrated normal opacification of the pulmonary arteries without pulmonary emboli. Other findings included large areas of necrotizing pneumonia in the lung bases, with adjacent complex pleural fluid. The right ventricle was enlarged consistent with right heart failure. There were no known complications from this study. Unfortunately, this patient eventually succumbed to his disease and died 3 weeks later.

Conclusion

To our knowledge, this is the first reported CTPA performed in an infant on VA ECMO using a portable CT. Obtaining a diagnostic CTPA in infants on VA ECMO with CT is challenging but feasible and provides an alternative to transferring patients between the PICU and radiology department. Hopefully, advances in portable imaging technology will continue to improve the feasibility, quality, and safety in imaging these critically ill patients.

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