Successful Use of Pulmonary Cryotherapy for Tracheobronchial Thrombus Extraction and Recanalization of the Tracheobronchial Tree During a Pediatric Venovenous Extracorporeal Membrane Oxygenation Run

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Impacted pediatric tracheobronchial thrombus is an uncommon diagnosis. There are no clearly proven therapeutic options for airway casts due to a similar process, plastic bronchitis. Cryotherapy, specifically cryoextraction, has shown potential as a therapeutic option in adults with tracheobronchial thrombus and cast. We describe the novel application of this method in a complex pediatric patient.

Keywords: cryotherapy, pediatric, tracheobronchial thrombus

Report

TO OUR KNOWLEDGE, this is the first reported pediatric use of pulmonary cryotherapy for refractory airway obstruction due to impacted tracheobronchial thrombus. There are no therapeutic options for the similar process of airway casts in plastic bronchitis.^{1,2} Cryotherapy employs compressed gas (nitrous oxide or carbon dioxide) delivered to a specialized catheter or cryoprobe, allowing for rapid cooling of the metal tip to temperatures near -89°C . Contact with the probe tip causes the liquid component of thrombus, secretions, or tissue to freeze resulting in cryoadherence within seconds. The probe may be advanced to the area of interest through a flexible bronchoscope side port or rigid bronchoscope. The operator can adjust the cryo effect through probe size, point of contact, and contact time. This technique has been utilized to perform extraction, tissue sampling, and relieve malignant obstruction in adult patients.³ The ERBECryoTM Probe (O.D 1.9 mm, 900 mm length) is currently the smallest available probe and allowed us to apply this technology in a pediatric patient. Our patient was a 27 kg 7-year-old girl with a history of DiGeorge Syndrome, Truncus Arteriosus, and right aortic arch. She underwent truncus repair as a neonate followed by right ventricle to pulmonary artery (RV-PA) conduit replacement

for stenosis (18 mm ring supported ContegraTM valve bovine jugular conduit) with truncal valve replacement for insufficiency (19 HP St. Jude[®] mechanical aortic prosthesis) at the age of 5 years. Her first operation was complicated by right main stem bronchomalacia, prolonged need for ventilator support, and recurrent aspiration requiring G-tube with Nissen fundoplication.

Despite her difficulties in early life, she was doing well on room air, Aspirin, enalapril, and warfarin in the outpatient setting. She presented with 1 week of diarrhea and fevers. Her examination was significant for a new harsh II/IV diastolic murmur in addition to a stable truncal valve click and II/VI systolic murmur of relative conduit stenosis. There were no rashes, specifically no Osler nodes nor Janeway lesions, appreciated. Laboratory evaluation revealed leukocytosis ($25,000 \text{ wbc/mm}^3$), thrombocytopenia ($9,000 \text{ plt/mm}^3$), and oxacillin-sensitive staph aureus bacteremia. Her bacteremia did not clear despite appropriate antibiotic therapy. Echocardiography revealed a $3.5 \times 4 \text{ mm}$ vegetation on the conduit valve and a $5.4 \times 3.2 \text{ mm}$ vegetation on the truncal valve. Shortly after admission, she developed rapidly progressive respiratory distress and hypotension prompting transfer to the cardiac intensive care unit and intubation. She suffered from worsening hypoxemia with bilateral opacification on chest radiography

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consistent with severe acute respiratory distress syndrome with probable septic emboli. Her hypoxemia was refractory to conventional and oscillatory ventilation, therefore, she was placed on venovenous extracorporeal membrane oxygenation (V-V ECMO) through the right internal jugular vein using a 23-French double-lumen Origen cannula attached to a system powered by a ROTAFLOW® pump with a Maquet Quadrox® oxygenator and heparin bonded circuit. She progressed to ECMO within 24 h of admission.

Her ECMO course was complicated by pulmonary hemorrhage with severely elevated peak pressures, limiting tidal volume delivery in a pressure-regulated volume control (PRVC) ventilation mode. Multiple daily flexible bronchoscopy evaluations revealed right main stem bronchus occlusion by persistent thick plugs of mucus with thrombus. These progressed to complete occlusion of the distal endotracheal tube (ETT) despite directly instilled mucolytic and frequent airway lavage. Three attempts at rigid bronchoscopy were performed using multiple devices, all of which resulted in temporary clearance of the airway with subsequent bleeding and return of occlusive thrombus with worsening impaction. All specimens returned as thrombus. The anticoagulation strategy was according to institutional protocol, targeting an activated partial thromboplastin time (PTT) of 60–90 s, or 2–3 times pre-ECMO baseline with prescribed adjustment metrics. We attempted 3 strategies to reduce bleeding during bronchoscopy. First, holding heparin for the procedure alone, second, a brief (50%) reduction of the infusion for 6 h, and third, holding heparin before (2 h) and after (4 h) rigid bronchoscopy. These strategies were unsuccessful. At this point, she was 25 days into a V-V ECMO run having made no significant progress in airway clearance or lung recruitment. This created a challenging clinical situation in which her airway obstruction and unknown underlying pulmonary function were precluding candidacy for RV-PA conduit replacement for her right heart endocarditis, an extremely high-risk operation with adequate pulmonary function. We then sought out alternative strategies to deal with this complex patient.

Interventional bronchoscopy with cryotherapy extraction has been employed with success in adult patients presenting with obstructing tracheobronchial thrombi.^{3–5} We reached out to our colleague at the University of Texas Southwestern Medical Center, an adult interventional pulmonologist, Dr. M. Abu-Hijleh, to aid in clearing her airways. Successful heparin-free V-V ECMO using a ROTAFLOW pump and Quadrox oxygenator has been described in adult and pediatric patients.^{6,7} To maximize the likelihood of procedural success, we discontinued heparin for the cryoextraction and remained off heparin for 3 days postprocedure with PTTs of 38 to 41.2 s. Low-dose (10 U/kg/h) heparin was restarted for the final 2 days of her ECMO run with PTTs ranging from 44 to 65 s.

Using an Olympus BF 190 EVIS Exera™ Bronchoscope (O.D. 4.2 mm), an ERBECryo™ Probe (O.D. 1.9 mm, 900 mm length) was advanced through her 5.5 ETT to the level of the obstructing thrombus. As our approach was limited by airway swelling and a palatal laceration, we were concerned that typical en bloc thrombus removal with ex-tubation would result in an inability to reintubate; therefore, the thrombus was extracted in a piecemeal manner. The left main stem bronchus was debrided to the level of the lobar bronchi during her first cryoextraction session. Owing to the

length of this meticulous procedure, we opted to address the right bronchial system the following day. The patient returned to the cardiac intensive care unit in a pressure control ventilator mode with tidal volumes improving from 5 to 10 mL preprocedure to 60–100 mL postprocedure (2–3 mL/kg). She underwent cryoextraction of the right bronchial system the following day wherein her tidal volumes improved to 140 mL (5 mL/kg) in a pressure control mode of 25 cmH₂O above a positive end expiratory pressure (PEEP) of 14 cmH₂O. The airways were completely patent to the segmental level after the second procedure. To avoid barotrauma and recruit atelectatic regions, she received 2 days of airway pressure release ventilation, then transitioned to PRVC ventilation with a tidal volume of 5 mL/kg above a PEEP of 14 cmH₂O, giving peak inspiratory and mean airway pressures of 30–35 and 20–22 cmH₂O, respectively. Her chest radiographs improved from complete bilateral opacification to a picture of diffuse chronic lung disease with improved aeration (Fig. 1) and PEEP was weaned to 12 cmH₂O. She had no further airway bleeding and was weaned from ECMO 5 days after her cryoextraction, day 30 of her V-V ECMO run.

Discussion

Acute airway obstruction due to an impacted tracheobronchial clot can be a life-threatening emergency. In the case of this complex patient, the obstructing tracheobronchial clot became a barrier to recovery, successful weaning from V-V ECMO, and ultimately operative treatment for her endocarditis. Existing methods for clot extraction include thrombolysis, mechanical debridement using foreign body basket, and other tools using rigid or flexible bronchoscopy. These methods include risk of bleeding, airway trauma, and failure to remove the clot, all of which occurred in the above mentioned case. Cryotherapy is an established method for achieving and/or maintaining airway patency due to obstructing tracheobronchial tumors and masses.³ The literature to date on the removal of obstructing tracheobronchial thrombus is limited and includes successful adult case reports and a single retrospective adult case series.^{3–5} In the retrospective case series of 38 cryoextraction sessions in 30 patients for indications of blood clot (26), mucous plugging (6), foreign body (4), and plastic bronchitis (2), Sritatanavirikayal and colleagues describe a high success rate in improvement in both airway patency and oxygenation.³ In the overall cohort, an increase in airway patency occurred in 32 of 38 patients (84%) of all sessions. Within the clot removal patient subgroup, the success rate for airway patency was higher at 24 of 26 (92%) sessions and showed improvement in oxygenation in 14 of 21 (67%) sessions performed.³ The incidence of complications was low with only 1 episode of hypotension in 1 of 38 patients treated for clot removal (2.6%).

We report the novel successful use of cryoextraction in a pediatric patient with total tracheobronchial tree obstruction using a piecemeal and staged approach. The use of cryotherapy in the pediatric population is limited by smaller ETT size and limited experience of pediatric pulmonologists with this modality. In this case, both of these factors affected our patient's clinical course resulting in a delay between identification of obstructing thrombus and application of cryoextraction. The use of cryotherapy through rigid bronchoscopy

FIG. 1. Two radiographs of the patient. The *left panel* shows the radiograph taken on the morning before the first cryotherapy session. The *right panel* shows the radiograph taken on the morning after the second and final cryotherapy session. A marked improvement in lung aeration was noted in the official radiology report.

for postpneumonia airway stenosis has been reported in a large series of Chinese pediatric patients (156) by Ni and colleagues.⁸ This was done with good success rates and a favorable safety profile. The cryotherapeutic approach to airway stenosis involves longer treatment time and/or greater cold exposure than cryoextraction.⁸ As smaller cryoprobes become available, further application of cryotherapy including cryoextraction is warranted in the pediatric population. This case supports the feasibility of using cryoextraction as a modality to recanalize the tracheobronchial tree after obstruction by a thrombus.

Acknowledgments

This patient received all of her care at Children's Health Dallas, Dallas, TX. Dr. Abu-Hijeh obtained emergency privileges to provide cryotherapy at Children's Health using cryotherapy probes provided on loan by the University of Texas Southwestern, Dallas, TX.

Consent

Informed consent was obtained from the patient's parents to publish the case information and accompanying images and laboratory studies.

Author Disclosure Statement

The authors have no financial relationships relevant to this article to disclose.

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