ABSTRACTS

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Author Index.................................................................................................... Pages 53–56

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Outcome after perioperative veno-venous extracorporeal life support as bridge to lung volume reduction surgery in patients with severe hypercapnia: a single-center prospective study ................................. 1
A 5 year retrospective study of electroencephalography and neurological outcomes children undergoing extracorporeal membrane oxygenation (ECMO) at a quaternary academic hospital setting ................. 1
Using Multidisciplinary Simulation to Improve Quality of Extracorporeal Cardiopulmonary Resuscitation ............................................................. 2
The two cases of the infants on ECMO with the “irreversible” myocarditis: How should we decide withdrawing ECMO treatment? .......... 2
Utilization of Transthoracic Echocardiography (TTE) in Pediatric Patients on Extra-Corporeal Life Support (ECLS) .................................................. 3
High body mass index (BMI) does not predict worsened outcomes in patients on veno-venous extracorporeal membrane oxygenation for acute respiratory distress syndrome (ARDS)............................... 4
ECMO Management Tool: iOS/Android App Assists with Large ECMO Program Coordination ................................................................. 4
Longevity of CardioHelp Disposable: A Case Report of 13 Weeks on Single ECMO Circuit with Minimal Anticoagulation ............................ 5
Neurologic Outcomes after Extracorporeal Membrane Oxygenation – a Practice Survey and Systematic Review ................................................. 5
Characteristics, Risk Factors & Outcomes of Extracorporeal Membrane Oxygenation use in the Pediatric Cardiac Intensive Care Unit ..... 6
Bedside ECMO Veno-Venous and Veno-Arterial Cannulation: bringing the treatment where is needed .......................................................... 6
Mechanical Cardiopulmonary Resuscitation and Veno-Arterial ECMO for treatment of deep hypothermia: the ‘impossible’ it’s happening.......................................................................................................... 7
Bedside ECMO Veno-Venous and Veno-Arterial Cannulation: bringing the treatment where is needed .......................................................... 7
ECPR: Can It Be Performed Safely In Unconventional Areas? A Case Review .............................................................................................. 8
Success, Nothing Less: Bridging the Educational Gap in a Moderately Busy ECMO Center ................................................................. 8
So You Want to Start a Pediatric ECMO (EXTRACORPOREAL MEMBRANE OXYGENATION) Program: Leadership, Administrative and Clinical Challenges ................................................................. 9
CRRT Access to ECMO Circuit and Associated Massive Hemorrhage .... 9
Evaluation of laboratory tests for monitoring hemostasis and hepatic therapy during pediatric extracorporeal membrane oxygenation .................................................................................................................. 10
Characterization of extracorporeal membrane oxygenation circuit thrombosis in pediatric patients ......................................................... 10
A Computational Model of Recirculation During Venovenous ECLS ...... 11
Developing Protocols to Decrease Incidence of Air Entrainment in ECMO Circuit Secondary to Free-Flow IV Tubing: An Analysis of Vanderbilt University Medical Center Adult ECMO Data .................................................. 11
Safety and Efficacy of Left Internal Jugular Bicaval Dual lumen catheter for Extracorporeal Membrane Oxygenation .................................... 12
VV ECMO as salvage therapy for ARDS secondary to Malaria .......... 12
Venoarterial Extracorporeal Life Support in Pediatric Diabetic Patient with Disseminated Mucormycosis ...................................................... 13
ECMO Case Study: Decision Making During Differential Diagnoses and Complications ................................................................. 13
Extracorporeal Membrane Oxygenation Characteristics and Outcomes in Adult Down Syndrome Patients ........................................... 14
Case Report: Successful use of pulmonary cryotherapy tracheobronchial thrombus debridement during a pediatric V-V ECMO run ........................................................................................................... 14
Using Anti-Xa levels to monitor anti-coagulation using UFH on ECMO: Are you killing your patient? ......................................................... 15
Impella Device as a Reliable Strategy to Unload the Left Ventricle During Peripheral Venoarterial Extracorporeal Membrane Oxygenation Support: The Massachusetts General Hospital Experience ..................................................................................... 15
In vitro comparison of two neonatal ECMO circuits using a roller or centrifugal pump with three different in-line hemoconcentrators for maintaining hemodynamic energy delivery to the patient .... 16
Neonatal Extracorporeal Membrane Oxygenation Sedation Practices: the four year experience ................................................................. 17
Increasing Staff Engagement Through the Creation of an ECMO Council ........................................................................................................ 17
Hematopoietic Stem Cell Transplantation on Veno-Arterial ECMO in a Pediatric Patient with Aplastic Anemia and Septic Shock ............ 18
Managing the Hypercoagulable ECLS Patient: An Opportunity for Improvement to the Registry ................................................................. 18
Survey of the American Pediatric Surgical Association on Cannulation Practices in Pediatric ECMO ............................................................. 19
Evaluating the Utility of the “Late ECMO Repair”: A Congenital Diaphragmatic Hernia Study Group Investigation ........................................ 19
Certification in ECLS for a Successful ECMO Program ............................................................................................................................... 20
Implementation of multidisciplinary ECMO team improves outcomes in high volume adult ECMO program .................................................... 20
Creating and Managing an ECMO Program Without a Perfusionist Team – The RN/RT Model ................................................................. 21
VA-ECMO for Post-Cardiotomy Cardiogenic Shock: The Oklahoma ECMO Network Experience ................................................................. 21
Indications for extracorporeal life support in congenital diaphragmatic hernia: What do our guidelines say? ........................................... 22
Aiming to Reduce Errors: Teaching Crisis Resource Management Skills during ECMO Simulation ................................................................ 22
“Use of venovenous ECMO in patients with Blastomycosis pneumonia: cases and considerations” .............................................................. 23
The Use of a CRRT Machine to Create Extracorporeal CO2 Removal in a Pediatric Patient ........................................................................... 24
An anti-Xa driven anticoagulation algorithm combined with routine replacement of antithrombin III is associated with reduced hemorrhagic and thrombotic complications as well as improved survival in post-operative pediatric patients supported with ECMO .... 24
ECMO strategy for severe ARDS complicated with septic shock ............ 25
No Increase in Risk by Delaying Decannulation .................................................. 25
ECMO Support for Pediatric Burn Patients: Is it Worth the Risk? .......... 26
Neonatal-Pediatric Extracorporeal Membrane Oxygenation (ECMO) in a Developing Latin American Country: 15 Year Experience in a Chilean ECMO Center ................................................................. 27
Cardiac Output Increases with Transfusion of Stored RBCs is partially offset with RBC Rejuvenation – A Simulation Study ...................... 27
Histopathologic Findings in Adult Recipients of Extracorporeal Membrane Oxygenation .......................................................... 28
Elevated initial regional brain oxygenation values may predict poor outcome in patients placed on veno-arterial ECMO .................. 28
Reposition of a dual lumen VV–ECMO cannula using a retrograde venous wire without disruption of extracorporeal support .......................................................... 29
Veno-Arterial Extracorporeal Membrane Oxygenation as Hemodynamic Support During Ventricular Tachycardia Ablation .......... 30
Using Interprofessional Simulation Training for developing a new Pediatric ECLS center .......................................................... 31
Hospital-Acquired Pressure Injury (HAPI) Prevention in Adult ECMO Patients ........................................................................ 31
Novel Leg Cannula for Venous Decompression in Peripheral Extracorporeal Membrane Oxygenation for Septic Adolescents ........ 32
Acute Kidney Injury, Fluid Overload, and Outcomes in Neonatal and Pediatric Patients Supported with Extracorporeal Membrane Oxygenation for Respiratory Failure .................................................. 32
Cardiac arrest caused by massive pulmonary embolism, survival using extracorporeal membrane oxygenator; a single center retrospective study ........................................................................... 33
Interhospital extracorporeal membrane oxygenation transport in a developing country .................................................................. 33
Volume overload, acute kidney injury, and fluid balance management in patients transferred to a large volume ECMO center .... 34
Exploring the Use of Extracorporeal Membrane Oxygenation (ECMO) as a Bridge to Organ Donation in a Pediatric Cardiac Patient: a Unique Case Report .......................................................... 34
Outcomes of ECMO Support as a Bridge TO or FROM Cardiac Transplantation .................................................................................. 35
In Vitro Evaluation of ECG-Synchronized Pulsatile Flow Using i-Cor Diagonal Pump in Neonatal and Pediatric ECLS Systems .... 36
Health related quality of life in long-term survivors after treatment with extracorporeal membrane oxygenation (ECMO) ............. 36
A challenging case of V-V ECMO ......................................................................................................................................................... 37
Coagulation for pediatric patients on ECMO: vWF and ADAMTS 13 ................................................................................................. 37
Plasma Arginase and Urea Cycle Intermediates in Pediatric Patients Requiring Extracorporeal Membrane Oxygenation (ECMO and CPB) .................................................................................................................. 38
Successful outcome of a patient treated with 5 different cardiac devices after cardiogenic shock due to myocardial infarction .......... 38
Is PEA a reason to refuse ECPR? .............................................................................................................................................................. 39
Nitrogen balance during veno-venous ECMO support – preliminary results of a prospective, observational study ...................... 39
Case report: former 23 week infant that experienced acute respiratory failure after retinopathy of prematurity (ROP) surgery that required extracorporeal membrane oxygenation (ECMO) ......................... 40
Speckle-tracking echocardiography in patients undergoing extracorporeal life support ................................................................. 40
The use of extra-corporeal membrane oxygenation in a pediatric patient with hepatopulmonary syndrome and interrupted inferior vena cava after living related liver donation ................................................................. 41
ECMO Management of Infants of Diabetic Mother with Persistent Pulmonary Hypertension of Newborn (PPHN) and Obstructive Hypertrophic Cardiomyopathy – A case series ................................................. 41
Adherence to a Mechanical Ventilation Protocol in Pediatric Patients Requiring VV-ECMO ................................................................ 42
ECMO for Hypoxic ischemic encephalopathy in neonates: Differences in attitudes between Neonatologist and Non – neonatologists ................................................................................................................. 42
Clinical Predictors of Safety and Efficacy of Veno-Venous Extra-Corporeal Life Support ................................................................. 43
Can ECMO facilitate a more conservative management strategy in lung abscess? ............................................................................. 43
ECMO Specialists’ Perceived Barriers to Pediatric Mobility ...................................................................................................................... 44
Use of FEIBA in the Setting of Massive Postoperative Hemorrhage in a Pediatric ECMO Patient ......................................................... 44
Creation of a pharmacokinetic model for optimal initial heparin dosing in pediatric patients receiving extracorporeal membrane oxygenation ........................................................................................................... 45
Ultrasound Use for ECLS Cannula Position in Children: Avoiding pitfalls in difficult situations .................................................................... 45
VA ECMO as a Bridge to Organ Transplantation: A Case Report ........................................................................................................... 46
The Columbia CTICU ECMO Bundle- Every ECMO Patient Every Time Quality Improvement for ECMO Cannula Safety and Infection Control during ECMO ......................................................................................... 46
In-Vitro Comparison of Hemodynamic Performance of Three ECLS Systems in an Adult Cardiogenic Shock Model ...................... 47
Evaluation of Hemodynamic Performance of a Combined ECLS and CRRT Circuit in Seven Positions with a Simulated Neonatal Patient .............................................................................................................. 47
In-vitro Hemodynamic Evaluation of ECG-Synchronized Pulsatile Flow in a Simulated Adult ECLS System .............................................................................................................................................................. 48
Retrospective review of hemolysis during pediatric extracorporeal membrane oxygenation with a centrifugal pump ................. 48
ECPR Simulation: Analysis of Quality CPR and ECPR Process Metrics from a Multidisciplinary Quality Improvement Project ........ 49
Retrospective Outcomes Analysis of ECMO Patients Antiocoagulated with Heparin vs. Bivalirudin .......................................................................................... 49
Outcomes of Central vs. Peripheral Veno-Arterial ECMO Cannulation: A Single Center Experience ................................................... 50
Case Report: Successful Recovery from Polysubstance Overdose Induced Circulatory Collapse with Venous-Arterial ECMO Support Initiated in ED ............................................................................................................. 50
It takes a Village to provide Advanced Physical Therapy: The Value of a Collaborative Early Mobility Program to restore Function for Patients on Extra Corporeal Membrane Oxygenation (ECMO) support .................................................................................................................................................. 51
Providing Early Rehabilitation and Ambulation to Adults on Percutaneous Venous to Arterial Extracorporeal Membrane Oxygenation Support .............................................................................................................. 51
Pediatric ECMO Mobility Requires An Interdisciplinary Culture Shift .......................................................................................................................... 51
A Retrospective Analysis of the Outcomes of Extracorporeal Cardiopulmonary Resuscitation (ECPR) ...................................................................................................................................................... 52
Outcome after perioperative veno-venous extracorporeal life support as bridge to lung volume reduction surgery in patients with severe hypercapnia: a single-center prospective study

Ali Akil, MD, and Stefan Fischer, Pr. Department of Thoracic Surgery and hypercapnia: a single-center prospective study

Background: Extracorporeal lung support (ECLS) represents an essential support tool especially for critically ill patients undergoing thoracic surgical procedures. Lung volume reduction surgery (LVRS) is an important treatment option for end-stage lung emphysema in carefully selected patients. Here we report our experience with the application of veno-venous ECLS as bridge to LVRS in patients with end-stage lung emphysema and severe hypercapnia.

Materials and Methods: Between January 2016 and March 2017, all patients with end-stage lung emphysema and severe hypercapnia due to acute failure of the breathing pump and which were bridged to LVRS using low-flow ECLS were included in this study. All data were prospectively recorded and retrospectively analyzed.

Results: N=51 patients (n= 23 female) with a mean age of 62 years (32–86 years) undergoing LVRS with veno-venous ECLS support were included and analyzed. In n=31 patients uniportal VATS-LVRS was performed. N=17 patients underwent bilateral LVRS. In n=5 patients v-v-ECLS was already implemented preoperatively. In n=46 cases v-v-ECLS was applied intraoperatively and continued postoperatively. Mean length of postoperative ECLS support was 3 days (1–14 days). In n=9 tracheostomy was performed preoperatively. From those patients n=4 patients were successfully weaned and decanulated during the postoperative course. The mean ICU stay was 13 days (1–62 days) and the postoperative hospital stay was 20 days (1–64). N=4 patients died due to disseminated intravascular coagulation (n=2) and sepsis (n=2). Postoperatively, a significant improvement was observed regarding the quality of life, exercise capacity and dyspnoea symptoms (Borg scale, all p <0.0001).

Conclusion: The application of veno-venous ECLS in patients with severe hypercapnia undergoing LVRS is an effective and well tolerated treatment option. In particular, it increases the intraoperative safety, supports de-escalation of ventilatory strategies, even in patients with tracheostomy and reduces the rate of postoperative complications such as re-intubation requiring respiratory failure.

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A 5 year retrospective study of electroencephalography and neurological outcomes children undergoing extracorporeal membrane oxygenation (ECMO) at a quaternary academic hospital setting.

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Background: Extracorporeal membrane oxygenation (ECMO) is a form of cardiopulmonary support that can be life saving for children with cardiac or respiratory failure. There is a high risk of neurological injury during ECMO including stroke. Recently, the risk of non-convulsive seizures has also been recognized. Our purpose was to analyze electroencephalogram (EEG) in order to predict imaging abnormalities in children requiring ECMO. We hypothesize that specific EEG patterns will predict abnormal imaging and mortality.

Methods: We retrospectively examined the utility of continuous EEG (CEEG) for ECMO in the intensive care units (ICU) at a quaternary care center when the protocol was recently revised to include to the use of CEEG on ECMO patients. We studied children ages 0–21 years undergoing ECMO between January 2010 and April 2015. Primary outcome measures were electrographic seizures (EGSz), abnormal brain imaging (ABI), and death.

Results: We reviewed 172 cannulations, of which 50 took place after the protocol change (Fig 1). Clinical seizures occurred in 23% (n=8); 3 without electrographic correlate. EGSz were recorded in 26% (n=10), 5 without clinical correlate. Status epilepticus occurred in 15% (n=5). Most seizures occurred >24 hrs after ECMO initiation; only 1 was within 6 hrs. Epileptiform discharges were seen in 43% (n=21), and 91% (n=31) had slowing. Imaging was abnormal in 41% (n=19) (Fig 1). CEEG findings such as focal attenuation, focal slowing, or epileptiform discharges correlated with ABI in 47% (n=8) of cases. There were 19 deaths (38%), and 40 survivors (80%). There was no correlation between arrest to cannulation time, or cannulation site and EGSz, ABI or death. There was a positive trend of EGSz with respiratory over cardiac failure (p=0.074, OR 4.4), but no difference in ABI or death. A longer duration of ECMO correlated with a higher death risk (p=.03), however, there was no trend in regards to EGSz or ABI. There was no significant correlation between EGSz and ABI (p=0.054, OR 7.3). There was no significant correlation between EEG or ABI and death.

Conclusions: Our CEEG data demonstrated clinical (23%) and EGSz (26%) in children on ECMO, many of which were subclinical. The risk of seizures in this cohort study are comparable to prior studies of seizures in ECMO patients, however, our cohort has a large number of patients with difficult-to-control seizures, frequently fulfilling criteria for status epilepticus. Stroke is also highly prevalent in this cohort, many with corresponding EEG abnormalities. The death rate was slightly higher the other reported studies, which is likely due to selection bias. ECMO is more often imposed on sicker, less stable patients in this specialized center. We found a higher risk of death with longer duration on ECMO. With further analysis we hope to identify EEG predictors for prognosis in this population, and teach future physicians about the neurological risks of ECMO improving morbidity and mortality.

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Using Multidisciplinary Simulation to Improve Quality of Extracorporeal Cardiopulmonary Resuscitation

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BACKGROUND: The use of extracorporeal cardiopulmonary resuscitation (ECPR) is increasingly reported in pediatric and adult patients who experience a witnessed cardiac arrest, primarily in the in-hospital setting. Multiple studies have shown that ECPR outcomes improve when a patient is cannulated onto extracorporeal membrane oxygenation (ECMO) within 30 minutes of a witnessed cardiac arrest, and that cardiac arrest outcomes are closely associated with the quality of CPR during the arrest. In 2015, a continuous quality improvement (cQI) project using ECPR simulations in an academic Pediatric Intensive Care Unit (PICU) was implemented. The goals of this project were to: identify and classify factors that may impede high quality CPR as well as those that contribute to delays in obtaining ECMO flow during ECPR simulations and to determine if the interventions implemented through this cQI project will eventually improve processes and outcomes in actual ECPR patients.

METHODS: A structured cQI project was implemented using the “four Es” (engage, educate, execute, evaluate) model. All disciplines involved in actual patient cannulations participated in the simulations. The in-situ simulations involved a high-fidelity simulated patient who experienced ventricular fibrillation cardiac arrest and underwent ECPR, with a neck skin/vessel model that allowed for connection of silicone “vessels” to the ECMO circuit and establishment of ECMO flow. An immediate debriefing followed each simulation to provide education and to identify opportunities for improvement. Recorded simulations took place every 1–2 months. Two independent reviewers analyzed the videos and the R-series Zoll defibrillator data for pre-determined ECPR process metrics such as time from onset of cardiac arrest to ECPR activation and time from onset of cardiac arrest to time on ECMO, and for pre-determined measures of quality CPR such as compression rate, depth, and compression fraction.

RESULTS: Preliminary results from 13 ECPR simulations conducted from 2015 to 2017 are being presented. The following opportunities for improvement categorized using crisis risk management principles were identified and addressed: 1) environment (implemented a room diagram for ECPR/ECMO cannulation, added sterile attire to code cart); 2) anticipation and planning (standardized pre-ECMO surgical consultation and vessel Doppler ultrasound); 3) mobilization (implemented a group page for ECPR/ECMO activation); 4) cognitive aides (developed checklists for team members by discipline); 5) workload distribution (designated roles for overall leader, quality CPR coach, “ECMO Communicator”). Further work will include a systematic review of all ECPR cases between 2012–2015 and 2015–2018, to conduct longitudinal data analysis to evaluate trends over time for CPR quality and ECPR activation processes metrics, and patient outcomes including survival and Pediatric Cerebral Performance Category at discharge versus admission.

DISCUSSION: Multidisciplinary ECPR simulations are feasible in the PICU environment. They have the potential for identifying opportunities for improvement that impact not only the ECMO program, but the functionality of the PICU team as a whole in crises other than ECPR including complex tasks such as central line placement or cardiac arrest without ECPR/ECMO activation.

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The two cases of the infants on ECMO with the “irreversible” myocarditis: How should we decide withdrawing ECMO treatment?

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Introduction: ECMO has remarkably progressed over the recent years and ECMO come to be applied for some patients with complex underlying diseases. Some of disease can be “irreversible” but it is difficult to judge whether they would be “irreversible” or not before ECMO initiation. Judging an ECMO patient, who is not indicated for transplant, to be “irreversible” during ECMO is equivalent to a death sentence, so irreparable evidence is needed. We experienced two cases of infants who needed ECMO due to acute “irreversible” myocarditis without chance to transplant and decided withdrawing ECMO treatment.

Case 1: A one-month-old baby boy was born by caesarean section on gestational age of 31 weeks because of threatened premature labor due to chorioamnionitis. One month after birth, he got hypothermia, cold extremities and tachycardia. During the day, mechanical ventilation was initiated because of worsening dyspnea. Acute myocarditis was diagnosed because ECG showed wide QRS and bigeminy, TTE showed reduced LV ejection fraction (EF) (31%), and blood examination showed higher creatine kinase (CK) (2800 IU/L) and elevated troponin T(TnT). Because of rapid deterioration, ECMO was initiated. As he got cardiopulmonary arrest, the surgeon started a central ECMO by means of the median sternotomy. On Day 12 after ECMO, ECG showed only P waves but no QRS waves so that temporary pacing by epicardial leads was initiated. Even with temporary pacing, there is no ventricular reaction and distended left ventricle was shown in direct view from the incision. LA venting catheter was inserted surgically. On Day 20, there was no recovery of ventricular function and then we decided to withdraw ECMO treatment.

Case 2: A 5-month-old baby girl was born on gestational age of 29 weeks and she was in the hospital for 4 months. One month later after discharge, she got vomiting and general fatigue. Acute myocarditis was diagnosed because of elevated CK and TnT on blood test, reduced RV and LV systolic function with pericardial effusion, and ST elevation at V1-V3 on ECG. RV and LV function was deteriorated and we decided to initiate ECMO. TTE showed reduced EF at LV and RV but no sign of LV distension through whole ECMO duration. The assessments on Day 28 after ECMO showed still no recovery. We did not identify evident signs of “irreversibility” and therefore myocardial scintigraphy ([137mTc]–201Tl, [123I]–BMIPP, [124I]–MIIBG) and CT scan were performed. The myocardial scintigraphy indicated reduced myocardial blood flow, decreased lipid metabolism, and extensive denervation of the sympathetic nerve. The chest CT scan revealed the calcification in extensive myocardium. Based on these finding, we decided to withdraw ECMO treatment on Day 41 after ECMO.

Discussion: Through these 2 cases, we had lots of discussion among multidisciplinary specialists, nurses and other medical staffs to obtain the consensus whether we should continued treatment or withdrawing based on the assessments of the available imaging or physiological examinations. We will mention the process how we judged “irreversibility” for acute myocarditis.

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therefore myocardial scintigraphy (201 still no recovery. We did not identify evident signs of “irreversibleness” and because of elevated CK and TnT on blood test, reduced RV and LV systolic function and then we decided to withdraw ECMO treatment.

A 5-month-old baby girl was born on gestational age of 29 weeks of rapid deterioration, ECMO was initiated. As he got cardiopulmonary arrest, the surgeon started a central ECMO by means of the median sternotomy. On Day 12 after ECMO, ECG showed only P waves but no QRS waves so that temporary pacing by epicardial leads was initiated. Even though the patient was still in poor condition, the patient was discharged. One month after discharge, the patient got hypothermia, cold extremeties and tachycardia. During the day, mechanical ventilation was needed ECMO due to acute “irreversible” myocarditis without chance to transplant and decided withdrawing ECMO treatment.

The two cases of the infants on ECMO with the “irreversible” myocarditis were unique. In the both cases, we judged “irreversibleness” for ED intervention. We will mention the process how we judged “irreversibleness” for ED intervention.

Introduction: Transthoracic echocardiography (TTE) is routinely used to determine cardiac anatomy and function in pediatric patients prior to initiation of ECLS. The role of TTE after initiation and before separation from ECLS is less well defined. We sought to determine the yield of TTE examinations during ECLS.

Method: Retrospective review of institutional ECLS database and digital TTE images from 2010–2015. TTE studies were guided by specific indication documented by intensive care specialist. Primary endpoint was yield, defined as clear and appropriate indication of TTE accompanied by TTE findings with greatest potential impact on clinical decisions. A Yield Score between 1–10, in order of ascending merit was assigned to each study after review of the clinical information, indication, TTE report and review of echocardiographic images by a single echo reader (AB). Data was analyzed using linear regression methods clustered around a unique patient and comparing VV with VA ECLS modalities.

Table 1. Distribution of indications for each ECLS modality (VA ECLS and VV ECLS) and combined ‘yield score’

<table>
<thead>
<tr>
<th>Indication (%)</th>
<th>Ventricular function (trial) n (%)</th>
<th>Ventricular function (no trial) n (%)</th>
<th>Cannula position n (%)</th>
<th>RV function/PA pressure n (%)</th>
<th>Atrial septal evaluation n (%)</th>
<th>Pericardial effusion n (%)</th>
<th>Other n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA ECLS (n=205)</td>
<td>65 (32)</td>
<td>36 (18)</td>
<td>38 (19)</td>
<td>16 (8)</td>
<td>13 (6)</td>
<td>8 (4)</td>
<td>29 (14)</td>
</tr>
<tr>
<td>VV ECLS (n=78)</td>
<td>10 (13)</td>
<td>11 (14)</td>
<td>28 (36)</td>
<td>16 (21)</td>
<td>1 (1)</td>
<td>5 (6)</td>
<td>7 (9)</td>
</tr>
<tr>
<td>‘Yield score’ per indication</td>
<td>6.0 ± 1.2</td>
<td>5.5 ± 1.8</td>
<td>7.6 ± 2.3</td>
<td>5.9 ± 1.3</td>
<td>7.8 ± 2.4</td>
<td>5.0 ± 2.8</td>
<td>6.5 ± 1.2</td>
</tr>
</tbody>
</table>

Results: A total of 284 interim TTE (average 3.2 ± 2.3 per patient) examinations were performed in a combined cohort of 88 patients with interesting differences in ‘yield’ based on indications for each modality (Table 1). Indications with the highest Yield Score were atrial septal evaluation (usually in the context of left ventricular distension and dysfunction) and cannula position (p<0.00). Of the 66 TTE done to recheck cannula position, 36(55%) had the highest yield score of 8–10, often guiding cannula repositioning. Evaluation for pericardial effusion received the lowest ‘yield’; only 2/12 had significant pericardial effusion.

Conclusion: The most common indications for TTE were for evaluation of cannula position and ventricular function whereas cannula position and atrial septal evaluation appear to have the highest yield. Echocardiographic assessment of ventricular function may be impacted by decreased preload and altered afterload during ECLS, reducing its interpretive ability. Modifications in critical care physician ordering practice, including identification of a precise clinical question, pre-TTE communication with an echocardiography specialist to optimize the acquisition of images and their interpretation, adjusting diagnostic information expectation may improve the diagnostic yield of TTE and reduce the number of unnecessary echocardiographic examinations.
High body mass index (BMI) does not predict worsened outcomes in patients on veno-venous extracorporeal membrane oxygenation for acute respiratory distress syndrome (ARDS).

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Objective: To characterize the impact of BMI on survival in patients receiving veno-venous ECMO support for acute respiratory distress syndrome (ARDS).

Methods: Adult patients with severe ARDS at a single institution supported with veno-venous ECMO from January 2014 through May 2017 were included. We evaluated the relationship of survival and BMI for each weight category (BMI <18.5, 18.5–24.9, 25–29.9, 30–39.9, and ≥40). The baseline PaO₂/FiO₂ ratio, Sequential Organ Failure Assessment (SOFA) and RESP scores were assessed in each BMI category to ensure similar baseline severity of illness.

Main Results: Of the 78 patients evaluated, the BMI ranged from 15.2 to 74.5. The average BMI of the cohort was 34.5, with 86% of the patients overweight with a BMI ≥25, and 65% of the patients obese with a BMI ≥30. There was no significant difference in PaO₂/FiO₂, SOFA score, or RESP Score between groups. The overall survival was 63% compared to a SOFA predicted survival of 45% and a RESP Score predicted survival of 69%. There was no difference in survival between different BMI groups.

Conclusions: A disproportionately large percent of patients requiring veno-venous ECMO for ARDS are overweight and obese. Fortunately, this does not appear to impact their overall survival compared to normal weight adults. Therefore, we should not consider BMI as a negative factor when deciding if a patient is appropriate for veno-venous ECMO support in the setting of ARDS.

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ECMO Management Tool: iOS/Android App Assists with Large ECMO Program Coordination

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Introduction: Efficient resource organization of large fast-paced regional ECMO referral centers can become a complex endeavor with patients, staff, equipment, and disposables moving throughout. Many equipment and staff trackers are currently on the market; while easy to use, most are costly and fail to integrate with patient needs and knowledge management for well-organized multidisciplinary healthcare administration.

Challenge: Currently over 225 ECMO patients per year are supported across four intensive care units within our 957 bed tertiary and quaternary academic hospital, not inclusive of nearly 100 periprocedural ECMO patients per year. As a regional referral center for complex cardiothoracic surgery, ECMO, VAD, transplant and trauma, approximately 100 patients are transferred on extracorporeal support from outside hospitals each year. With a total of over 300 ECMO patients traversing our institution over the course of one year, more than 20 pumps with associated disposables to maintain and a very large multidisciplinary healthcare team including 70 staff (perfusioneers and respiratory therapists) acting as ECMO Specialists with primary job duties elsewhere, we sought a cost neutral tool to assist with efficient resource management.

Needs Assessment: We desired to have the following capabilities: 1) display device location, identification, and maintenance information 2) show a snap shot of utilization of resources by each patient (i.e. acuity of patient, devices in use, human power needs such as planned procedures or ambulation) 3) track disposable inventory and create par level alerts for re-ordering 4) a portal with easy staff access to knowledge management such as cognitive aids, current policies and procedures, real time updates, and upcoming continuing education 5) accessible on iOS or Android smart phone, or from a secure website 6) free download, license or covered by a current institutional license.

Solution: A number of potential options for resource management were evaluated. These included tools within the electronic medical record, device and staff tracking systems, and a number of available apps for iOS and Android users. The program which most closely met our needs was Microsoft Power Apps. After extensive customization, the “Duke ECMO App” was self-designed to better manage our resource use and needs, without the use of protected health information, and with secure institutional log in.

(To be included in presentation: instructions for customization to individual institution and screen shots of the “Duke ECMO App” in use.)

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Neurologic Outcomes after Extracorporeal Membrane Oxygenation – a Practice Survey and Systematic Review
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Introduction: Neurologic injury is a significant cause of morbidity among ECMO survivors. An estimated 10%-60% of ECMO survivors have neurologic disability long-term. The aim of this survey and systematic literature review was to determine the types of neurodevelopmental follow-up offered to families of pediatric ECMO patients in current practice in pediatric academic centers, to determine the most widely used outcome measures in pediatric ECMO studies, and to inform selection of outcome measures for future studies.

Methods: Survey. We conducted an anonymous, single cross-sectional survey of members of the Pediatric Neurocritical Care Research Group (PNCRG) and the ECMO subgroup of the Pediatric Acute Lung Injury and Sepsis Investigators (PALISI). Systematic Review. We conducted electronic searches of PubMed, Web of Science, CINAHL, Cochrane and EMBASE in November 2016, using a combination of medical subject headings and text words to capture concepts of extracorporeal life support and neurologic outcomes. Inclusion criteria included publication between January 1, 2000 and November 30, 2016, age 0 to 18 years and use of a standardized measure to evaluate neurodevelopmental outcomes. We excluded case series of less than ten patients and studies that did not report primary data.

Results: Survey. Of the 66 surveys sent, we received complete responses from 24 institutions (36%). Ten of 24 (42%) institutions had a neuro-monitoring protocol in place. After decannulation from ECMO, 22/24 institutions (92%) obtained a follow-up MRI on select patients. Follow-up clinics for former ECMO patients were available at 9 (38%) institutions. Systematic Review. The electronic literature search identified 3497 unique citations; 60 full-text articles were included in the final review. Studies evaluated patients with congenital diaphragmatic hernia (7), cardiac disease (8), cardiac arrest/ECPR (13) and mixed populations (32). Neurologic evaluations were conducted at hospital discharge in 10 (17%) studies and at a median of 26 months (IQR, 8–61 months) after ECMO in 50 (83%) studies. We found 50 distinct outcome measures used to evaluate neurodevelopmental outcomes of pediatric ECMO patients. The measures assessed overall health and function (4), cognitive ability (10), development (3), motor function (4), adaptive behavior (6), hearing (2), quality of life (2), school achievement (3), vision/coordination (1), speech and language (6), learning, memory and attention (9) and executive function (2). The most commonly used outcome measure was the Pediatric Cerebral Performance Category (18 studies), followed by the Wechsler Preschool and Primary Scale of Intelligence (11). Cognitive ability was less affected than functional domains like attention and memory.

Conclusions: A better understanding of the full spectrum of neurologic injury incurred during ECMO, and of long-term neurologic outcomes of ECMO patients is greatly needed. To improve outcomes after ECMO, a commitment to improving techniques for monitoring and preventing neurologic injury is essential, along with rigorous and collaborative plans for evaluating patients’ long-term cognitive, motor, developmental and behavioral outcomes.

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Longevity of CardioHelp Disposable: A Case Report of 13 Weeks on Single ECMO Circuit with Minimal Anticoagulation
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Introduction: Extracorporeal membrane oxygenation (ECMO) support may be complicated by limitations in circuit longevity as well as anticoagulation strategy. Universal consensus has not been reached regarding ECMO anticoagulation nor criteria and methods for elective ECMO circuit change. Frequent ECMO circuit changes increase the financial burden of ECMO support and risk to the patient. Circuit longevity may be influenced by circuit design, anticoagulation strategy, blood flow rates, and patient physiology.

Case Presentation: A 43-year-old man with no significant previous medical history presented with 2 weeks of shortness of breath, cough, fevers, chills, and chest tightness. He did not improve despite a course of oral levofloxacin, and presented with oxygen saturations in 60s. Chest radiograph showed diffuse bilateral infiltrates. The patient failed biPAP, was intubated and started on vancomycin, ceftriaxone, and azithromycin in addition to norepinephrine for hypotension. Echocardiogram was normal. Respiratory viral panel, blood, urine, and sputum cultures all returned negative. Despite high levels of ventilator support with PEEP of 20 and FiO2 of 100%, the patient continued to have worsening hypoxic and hypercarbic respiratory failure. Due to escalating oxygen requirements despite high ventilator settings and worsening arterial blood gas (pH 7.15, pCO2 72, pO2 73), the patient was remotely cannulated for venovenous ECMO via right internal jugular and right femoral veins, supported with Maquet CardioHelp HLS (Bioline) 7.0 and transferred to a regional ECMO referral center.

The patient remained critical on venovenous ECMO, intermittently requiring vasoactive agents. ECMO flows of 3–4 LPM were maintained for the first two weeks of support. The patient then required additional ECMO support of >5LPM to maintain consistent SpO2>75%. Recirculation was ruled out and oxygen transfer confirmed satisfactory across the oxygenator. Lungs remained severely impaired with no evidence of improvement, so a lung transplant workup was initiated. Lung transplant was not an option, because the patient was unable to actively participate in pre-transplant physical conditioning due to deconditioning, instability, and oxygen requirements.

In addition, the patient did not tolerate intravenous anticoagulation and remained on subcutaneous heparin for the course of ECMO. No significant ECMO circuit fibrin or clot formation was noted. The patient’s imaging, hemodynamic, and ventilatory data all suggested no interval improvement. On ECMO day 73, although additional options were provided, it was decided not to further escalate care, and the patient was made DNAR. On ECMO day 90 the patient died from a bradycardic PEA arrest. After pronouncement of death, and with permission of the family, the ECMO circuit flow was stopped and disconnected from the patient. The circuit was washed with 3L normal saline, the CardioHelp assembly carefully disassembled for evaluation, and digital images taken. Review of post-support circuit reveal significant deposits on pre-membrane face of oxygenator in portions not visible during ECMO support. Post-membrane deposits are minimal.

Discussion: The patient was supported on VV ECMO with flows ranging from 3–6LPM with subcutaneous heparin anticoagulation on a single CardioHelp disposable for 2,147 hours. Intermittent post-membrane circuit gas analyses taken in the last weeks of support reveal continued excellent oxygen transfer. To our knowledge, this is the longest reported use of a single disposable for extracorporeal support with minimal anticoagulation. This case illustrates the potential for alternative anticoagulation strategies as well as advanced longevity of devices currently FDA approved for only 6 hours. (To be included in presentation: graphs of ECMO course flows and anticoagulation, tables of patient arterial blood gas, post-membrane circuit gas, and coagulation laboratory results, and images of post-support oxygenator)

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**Characteristics, Risk Factors & Outcomes of Extracorporeal Membrane Oxygenation use in the Pediatric Cardiac Intensive Care Unit**


**Background:** Extracorporeal Membrane Oxygenation (ECMO) is used to support pediatric patients with medical and surgical cardiac disease. We aimed to characterize ECMO use across a multicenter cardiac cohort.

**Methods:** Retrospective analysis of the Pediatric Cardiac Critical Care Consortium (PC4) clinical registry was performed to describe ECMO frequency and outcomes. Within strata of medical and surgical hospitalizations, we identified risk factors associated with ECMO use through multivariate logistic regression.

**Results:** Across 23 hospitals, there were 14,526 eligible hospitalizations from 8/1/14–6/30/16, of which 449 (3.1%) included at least 1 ECMO course. ECMO was used in 120 (2.4%) medical and 329 (3.5%) surgical hospitalizations. Low cardiac output was the most common ECMO indication in both groups. Extracorporeal cardiopulmonary resuscitation (E-CPR) was used in 42% of medical and 32% of surgical ECMO courses. Risk factors associated with ECMO use in the medical group included acute heart failure and higher vasoactive inotropic score at admission (both p<0.0001). Stroke (15%) and renal failure (15%) were the most common ECMO complications in the medical group. Risk factors associated with post-operative ECMO use in the surgical group included younger age, extracardiac anomalies, pre-operative morbidity, higher STAT category, bypass time, and early post-operative mechanical ventilation and arrhythmias (within 2 hours) (all p<0.05). Bleeding requiring re-operation (25%) was the most common ECMO complication in the surgical group. Hospital mortality was 63% in the medical group and 50% in the surgical group with E-CPR mortality rates of 83% and 50%, respectively.

**Conclusion:** This is the first multicenter study describing contemporary ECMO use and outcomes in pediatric CICU patients with all forms of cardiac disease. ECMO is a rare therapy, yet mortality remains high, highlighting the importance of identifying levers to improve care. We identified unique high-risk subgroups to target for quality initiatives within medical and surgical patients.

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**Bedside ECMO Veno-Venous and Veno-Arterial Cannulation: bringing the treatment where it is needed.**

Domenico Calceterra MD PhD1, Beth Heather RN2, Dirk Rilla CCP2, Matthew Prekker MD2. Minneapolis Heart Institute at Abbott Northwestern Hospital1 and Hennepin County Medical Center2. Minneapolis, MN, USA.

**Objectives:** Cannulation arguably represents the key factor for the success of Extracorporeal Membrane Oxygenation therapy. Cannulation is traditionally accomplished in the operating room or the Cath Lab to ensure safe cannulation, obtain adequate cannula positioning and minimize complications. Nonetheless, patients’ critical and unstable conditions are often non-favorable to patients’ transport, which can also cause a significant delay in the initiation of therapy. With the objective of minimizing these downsides we established a protocol of “in situ” cannulation where the ECMO cannulation is accomplished at the bedside.

**Methods:** between June 2015 and April 2017, 16 consecutive patients underwent bedside cannulation. Fourteen were cannulated in the Intensive Care Unit and 2 in the Emergency Department.

**Results:** there were 9 Veno-Venous (VV) and 7 Veno-Arterial (VA), 9 males and 7 females, mean age 39 (12–69). Survival with full recovery was achieved in 12 patients (75%). Average ECMO support was 8 days (1–25). There was one cannula malposition which required repositioning in the operating room. There were no deaths or major complications related to cannulation.

**Conclusions:** bedside VV and VA cannulation is safe and effective. It allows faster initiation of therapy minimizing the hazards and delays related to patients’ transport from site to site with the potential benefit of improved outcomes and cost-savings.

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**Mechanical Cardiopulmonary Resuscitation and Veno-Arterial ECMO for treatment of deep hypothermia: the ‘impossible’ it’s happening.**

Domenico Calcaterra MD PhD1, Beth Heather RN2, Dirk Rilla CCP.

**Objectives:** CPR during hypothermia is hazardous. Our previous experience shows that CPR stopped after 20 minutes was unsuccessful, resulting in death. The aim of the present study was to determine the feasibility and efficacy of mechanical chest compressions combined with extracorporeal life support.

**Methods:** Between October 2015 and January 2017, 5 patients underwent CPR and ECMO for treatment of deep hypothermia. There were 3 males and 2 females, mean age 42 (31–55). Mean core body temperature at time of hospital admission was 22 degrees (17–25). Chest compression was performed by Lucas® in 4 patients. One patient had full recovery with no neurologic deficits. One patients required limbs amputation.

**Results:** there were 3 males and 2 females, mean age 42 (31–55). Mean core body temperature at time of hospital admission was 22 degrees (17–25). Chest compression was performed by Lucas® in 4 patients. One patient had full recovery with no neurologic deficits. One patients required limbs amputation.

**Conclusions:** Extracorporeal life support combined with mechanical chest compressions is a reproducible therapy in the treatment of deep hypothermia patients with a favorable outcome.

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Objectives: victims of hypothermia are subject to cardiac arrest once core body temperature drops below 32 degrees Celsius. Cardiopulmonary resuscitation and active rewarming are the mainstay of treatment followed by electric cardioversion. Despite long resuscitation times, organs’ protection provided by hypothermia can positively impact on survival.

Methods: between October 2015 and January 2017, 5 patients underwent mechanical cardiopulmonary resuscitation using LUCAS® Chest Compression System and Veno-Arterial (VA) ECMO rewarming after been hospitalized with cardiac arrest secondary to deep hypothermia.

Results: there were 3 males and 2 females, mean age 42 (31–55). Mean core body temperature at time of hospital admission was 22 degrees Celsius (19–25). Cardiopulmonary resuscitation by means of mechanical chest compression was performed by Lucas® in 4 patients. One patient had sinus bradycardia with intermittent ventricular fibrillation causing cardiogenic shock. The mean cardiopulmonary resuscitation time in 4 patients prior to establish circulatory support with VA ECMO was 175 mins (65–231). VA ECMO support was required for a mean of 23 hours (0.6–58). All patients were successfully cardioverted to sinus rhythm and had full recovery with no neurologic deficits. One patients required limbs amputations from frostbite.

Conclusions: VA ECMO and mechanical chest compression allowed resuscitation from deep hypothermic cardiac arrest with no mortality and full neurologic recovery despite extremely long cardiac arrest time. Occasional survivals after prolonged cardiac arrest with profound hypothermia have been reported anecdotally, nonetheless our experience shows that the combination of these resuscitation tools could make such results reproducible in much larger scale than anticipated.

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ECPR: Can It Be Performed Safely In Unconventional Areas? A Case Review
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Introduction: Historically at the Medical University of South Carolina, the emergent deployment of ECMO for an actively arresting pediatric patient has been restricted to the three intensive care unit settings within the Children’s Hospital. The ECPR program was established with initiation criteria inclusive of the geographic designations of these three ICUs to ensure all involved staff would be sufficiently trained and accustomed to the clinical scenarios introduced by this unique and complicated patient population. However in early 2016, the opportunity presented itself to reconsider the efficacy of ECPR in non-traditional areas of our organization and examine the appropriateness of emergently deploying ECMO for actively arresting patients despite their location within our hospital.

Case: A four year old male with a known history of restrictive cardiomyopathy presented to the outpatient, pediatric procedural area (PPA) within our health care system for planned dental rehabilitation. At the time of presentation, the patient was designated as 1A for heart transplant, and dental caries in question to prevent the opportunistic risk of endocarditis during the immediate post-transplant period. Prior to induction of anesthesia, he was administered appropriate doses of both ketamine and versed, started on 5 mcg/kg/min of dopamine, and nasally intubated. Upon induction of procedural anesthesia, he immediately demonstrated difficulty with ventilation and oxygenation, presenting with fulminant pulmonary edema. His cardiopulmonary status continued to decline despite multiple pharmacologic and diagnostic interventions; ultimately resulting in cardiac arrest. CPR was initiated and central venous access obtained. Cardiothoracic Surgery was summoned to the PPA, and ECPR was initiated. The first skin incision for ECMO cannulation was made 9 minutes after ECMO was deployed. After a total of 52 minutes of CPR in the PPA, the patient was placed successfully on VA ECMO via 16 Fr RIJ cannula and a 14 Fr RCCA cannula. He was transferred to the Pediatric Cardiac ICU for management. His ECLS support was delivered through the usual fashion with the employment of our center’s centrifugal pump and oxygenator. He received 12 days of ECLS support and was then transitioned to BIVAD support until he subsequently received a donor heart 24 days later. He was discharged from our ECMO center without neurologic deficits despite his prolonged CPR time in a non-ICU setting.

Conclusion: ECPR can be safely implemented and performed in unconventional areas within a health care system. Timely communication paired with skilled staff can facilitate the effective deployment of life saving ECMO support for the actively arresting patient.

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Success, Nothing Less: Bridging the Educational Gap in a Moderately Busy ECMO Center
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Introduction: Traditionally, the ECMO Program at the Medical University of South Carolina has experienced an average, annual case load of 20–25 patients inclusive of the Children’s and Main Hospitals. While the number of patients has grown exponentially since the inception of the program, the educational model in place did not simultaneously evolve to meet the increased needs of the ECMO Team. Utilizing both centrifugal and roller head technology to deliver ECLS support, the ECMO Specialists within our center were found to have a decreased level of comfort with safely managing both modalities in relation to the current caseloads. The preexisting educational platform from which education for competency was delivered was a bi-annual format, encompassing a water drill for each system once per year. This was deemed to no longer be effective, and the need for a complete revision of the educational model became apparent.

Method: A complete analysis of all available ECMO education for our center was performed to assess the content and quality of the product currently in place. Upon completion of the original analysis, clear and consistent insufficiencies were found to be present among all members of the ECMO Team. The level of comfort at the bedside was found to be insubstantial. Therefore, a complete revision of the existing educational model occurred, and the bi-annual water drills were discontinued. The ECMO Leadership Team developed ECMO clinical scenarios and paired them with our center’s ECMO and simulation equipment. The ECMO Team consisting of 25 staff members was then introduced to quarterly simulation check-offs, alternating between each of the two ECMO systems within our center. This new model would ensure all ECMO Team members have direct time and experience with each system, independent of annual patient volumes. As time progressed, simulation scenarios grew in intensity and depth, eliciting responses from the ECMO Specialists that were more critical in nature. The comfort level of the ECMO Team with both ECLS systems grew substantially over time as their guaranteed increased exposure to the systems continued.

Conclusion: ECMO education in moderately busy ECMO centers must be ever evolving and changing to meet the demands that are being placed upon staff employing the various modalities. This will ensure a higher level of safety and expertise at the bedside for those delivering and receiving this high risk therapy.

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So You Want to Start a Pediatric ECMO (EXTRACORPOREAL MEMBRANE OXYGENATION) Program: Leadership, Administrative and Clinical Challenges
Dominick M. Carella RN MSN MBA and Shaheen Timmapuri MD

Background: The institutional requirements for the establishment of an ECMO program have been well-described and developed by the Extracorporeal Life Support Organization (ELSO). This present look not only outlines and considers the personnel and capacity resources, but the financial impact model as well. The state of New Jersey has approximately 100,000 births per year. The common congenital conditions that require ECMO service include: congenital diaphragmatic hernia (1 in 5000 births), congenital pulmonary artery malformation (0.66 per 10,000 births), and congenital persistent pulmonary hypertension (2 per 1,000 live births), with the acquired conditions including, but not limited severe viral or bacterial pneumonia.

Methods: Conservatively, we estimate 21 pediatric patients in the state of New Jersey (NJ) needing ECMO every year. We estimate that we will capture 1/3 of the market the first year (7 cases), ½ of the market in the second year (11 cases) and we will peak at 70% (14 cases) in subsequent years. A conservative estimate is 7 days of ECMO run per case. These statistics will serve as the basis for revenue projection.

Results: The utilization rate for ECMO for NJ pediatric patients increased 40% between 2013 and 2014 with three-quarters of the ECMO procedures for NJ pediatric residents performed at out-of-state hospitals. The NJ ECMO pediatric utilization rate is consistent with projections using national averages based on payer mix and length of stay.

Conclusions: It is assumed that mechanical circulatory support loses revenue, but applicable current procedural terminology coding descriptions align themselves toward profitability if a true clinical need from an appropriate treatment decision making construct exists. It is important to note that The Centers for Medicare & Medicaid Services is proposing to cut the reimbursement rates for treatment with certain single chamber heart pumps but is adding coverage for use of the pump in both chambers of the heart.

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CRRT Access to ECMO Circuit and Associated Massive Hemorrhage
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Mentor: Jesse T. Lester, MD Critical Care Anesthesiologist, Ohio State University WMC

Case Description: 32yo M with PMHx significant for pulmonary atresia and cardiomyalgia s/p homograft repair x 2 (ages 3 and 15.) He was lost to follow-up at age 18 until he presented with acute decompensated heart failure. TTE on admission was significant for dilated LV with EF 35%, severely dilated ascending aorta, severe aortic regurgitation, and severe pulmonary valve regurgitation with mildly reduced RV function.

On hospital day #5 he was taken to the OR for redo sternotomy, AVR/Bentall, and PV replacement. The patient (pt) was placed on V-A ECMO support via his R axillary graft and L femoral venous cannula due to cardiogenic and vasoplegic shock after a prolonged CPB run. His chest was left open due to severe coagulopathy. On POD#0–1, the R axillary cannula was urgently changed to a R femoral arterial cannula due to severe RUE swelling. On POD#1 he developed RLE ischemia for which he was taken back to the OR, centrally cannulated and a RLE fasciotomy was performed by vascular surgery. He was also started on CRRT via the ECMO circuit for hyperkalemia, metabolic acidosis, and anuric AKI.

On POD#2, the pt was noted to have discrepant pupil size and remained minimally responsive. A stat CT head was ordered. In preparation for transport, his CRRT was stopped and the cassette ejected from the roller pump. Shortly thereafter, he developed severe hypotension and low ECMO flow. On initial evaluation, he appeared dusky. As aggressive resuscitation with fluids and epinephrine was initiated, it was noted that the CRRT fluid bag was filled with blood. Massive transfusion protocol was initiated. On inspection of his ECMO and CRRT circuits, it was noted that the stopcock of the CRRT inflow was not closed to the ECMO circuit. Given that the CRRT cassette had been removed from its roller pump, flow from the high pressurized (post-pump) ECMO circuit was no longer regulated by the roller pump itself, and was free to flow into the low pressure CRRT fluid bags, resulting in massive hemorrhage. After this was corrected and he was stabilized, a stat CT head revealed massive ischemic CVA with associated herniation. These findings were discussed with family, and the pt was transitioned to comfort care and expired.

Discussions: CRRT circuits can be directly connected to ECMO circuits, simplifying access for the pt, and negating need for another large venous line in an anticoagulated pt. However, this technique is not without its own inherent risks. A thorough understanding of the connections involved and the flow principles in question is paramount to optimize pt safety. This is especially relevant when manipulating or troubleshooting the circuits. Proper training of all involved in the care of these pts (RNs, perfusionists, physicians) as well as the presence of appropriate personnel for manipulation of the circuits is essential.

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Evaluation of laboratory tests for monitoring hemostasis and heparin therapy during pediatric extracorporeal membrane oxygenation

Nabija Huq Saifee, Chris Burke, Robert Mazor, Thomas Brogan, Wayne L. Chandler, Seattle Children’s Hospital, BloodWorks Northwest

Background: Close monitoring of heparin anticoagulation for patients on extracorporeal membrane oxygenation (ECMO) is critical to avoid life-threatening bleeding and thrombosis. Commonly utilized tests for heparin monitoring include the activated clotting time (ACT), partial thromboplastin time (PTT), and anti-Xa (aXa) heparin activity. Both the ACT and PTT are clot-based assays initiated by contact factor activation, but the ACT requires fresh, whole-blood specimens whereas the PTT requires citrated plasma. The aXa heparin activity assay is a plasma-based chromogenic assay that measures antithrombin-heparin complex activity. In this study, we compared the most commonly utilized heparin monitoring tests in pediatric patients on ECMO therapy.

Methods: The study was approved by the IRB at Seattle Children’s Hospital. Demographics: 39 patients, 40 ECMO runs, age 1 day to 20 years (median 6 months old), 20 males, 19 females, ECMO duration 1 to 47 days (median 4 days), 29 VA and 11 VV ECMO, 23 survived to discharge, 2 survived to decannulation, 14 died on ECMO. Laboratory results for ACT, PTT, aXa heparin activity, prothrombin time (PT), fibrinogen, hematocrit (HCT), platelet count (PLT) were collected.

Results: As a whole-blood assay, the ACT samples contained varying levels of plasma depending on patient HCT which ranged from 15.6 to 59%. Even though variations in patient HCT varied the amount of plasma and thus fibrinogen and coagulation factors in ACT assay samples, the ACT results were still affected by coagulation factor levels as indicated by moderate inverse correlations with PT (r = 0.60, range 12.2 to 41 sec, r²=0.25) and weaker inverse correlation with fibrinogen (r = 0.57, range <40 to 986 mg/dL, r²=0.12). The ACT was also affected by platelet counts with higher counts associated with lower ACT (r = 0.60, range <10,000 to 318,000/μL, r²=0.098). While the ACT showed a strong positive correlation with PTT (r = 0.77, range 27 to 200 sec, r²=0.49), there was no correlation between ACT and aXa heparin activity (r = 0.10, range <0.10 to 1.1 aXa U/mL, r²=0.005) and only a weak correlation between PTT and aXa heparin activity (r²=0.13).

Discussion: Historically, serial monitoring of ACT levels has been the most common method utilized for heparin monitoring in patients on ECMO. In this study we found that higher coagulation factor levels as indicated by shorter PT and higher fibrinogen tended to shorten the ACT as expected. The ACT was also shortened by high platelet counts, possibly as a result of accelerated clotting on the activated platelet phospholipid surface and/or fibrinogen neutralization by platelets. While the ACT was strongly correlated with the PTT, the ACT showed no correlation with aXa heparin activity and the PTT showed only a weak correlation with aXa heparin activity. The correlation between ACT and PTT may be related to use of contact activation in both assays.

Conclusions: The ACT is affected by variations in multiple parameters including coagulation factor levels, platelet counts, and contact activation. Variations in HCT result in further ACT variation by altering the amount of plasma factors in the assay. The lack of correlation between ACT and aXa heparin activity results for pediatric patients on ECMO may in part be due to the ACT’s sensitivity to variations in other blood parameters.

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Characterization of extracorporeal membrane oxygenation circuit thrombosis in pediatric patients

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Background: Thrombus development in extracorporeal membrane oxygenation (ECMO) circuits is a common complication. Thrombus development has been associated with degradation of circuit oxygenation, hemolysis and arterial embolization, often resulting in the need for circuit replacement. To reduce the risk of ECMO circuit thrombus it is important to understand how and where circuit thrombi form.

Methods: We surveyed the sites and extent of ECMO circuit thrombi in 20 circuits from 15 patients (age 1 day to 20 years, median 16 months). In 12 of the circuits, thrombi were evaluated for histologic structure including distribution of tissue factor, fibrin and von Willebrand factor (VWF) using immunohistochemistry.

Results: 90% of circuits showed tubing thrombi (45% arterial, 10% venous, 15% post-pump, 45% connectors), starting with a layer of fibrin at the tubing surface with minimal VWF or tissue factor, suggesting thrombin-mediated, surface activation and flow related mechanisms. Tubing thrombi expanded up to 2 cm in size by trapping red cells, white cells and platelets. One thrombus embolized to the pump. Oxygenator membranes showed microscopic fibrin formation that was usually not associated with oxygenator degradation, except in one case where a dense, firmly attached fibrin clot formed over the entire inflow oxygenator membrane resulting in oxygenator failure and circuit replacement in a hypercoagulable patient with recurrent venous thrombosis. In 20% of oxygenators, clots were noted on the inflow and/or outflow sides in low flow areas. Two patients receiving antifibrinolytic therapy showed unusual thrombosis forming on the oxygenator membrane surface and plastic supports. In one case, clotting was extensive extending the full membrane thickness from the inflow to outflow side. 90% of circuits showed thrombus on the exposed metal of the pump axle, consisting of layers of compressed, degraded fibrin, VWF and red cells that were unstable resulting in fragmentation with trapping of the clot fragments by the oxygenator. The extent of pump fragments correlated with the duration of ECMO, and a slight increase in delta pressure but not with plasma hemoglobin, and appeared benign in most cases.

Conclusions: Clinically the most significant circuit thrombi were 1) adherent clot on oxygenator surface leading to failure, 2) dense membrane clots associated with antifibrinolytic therapy and 3) large arterial tubing and connector thrombi. Tubing and oxygenator clots started with fibrin at the surface with little tissue factor, VWF or platelets suggesting thrombin mediated, surface activation and flow related mechanisms. Common but less significant were venous and pump tubing clots, and pump axle clots that produced clot fragments trapped in the oxygenator. Further reducing or blocking activation of coagulation on the circuit surfaces is the most likely approach to reduce circuit thrombi.

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A Computational Model of Recirculation During Venovenous ECLS

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Venovenous extracorporeal life support (VV-ECLS) is associated with varying degrees of recirculation, resulting in a reduction in effective blood flow. Although the general factors contributing to recirculation are recognized, a detailed analysis has not been performed. This project aims to systematically study recirculation and the factors contributing to it such as cannula position, ECLS blood flow rates and cardiac parameters, using a computational model to better predict and minimize it.

A 3D model of the right atrium and vena cavae was constructed that incorporated computational fluid dynamics (CFD) and fluid-structure interaction (FSI). The RA geometry was obtained by 3D surface reconstruction from slices of a contrast CT of the chest using InVesalius (Renato Archer Information, Campinas SP, Brazil). A surface mesh was developed and shelled with a 2-mm offset using MeshLab (ISTI-CNR, Pisa, Italy) to represent the atrial wall, and imported into COMSOL Multiphysics® v5.3 to create the solid geometry consisting of vascular and atrial walls and an interior blood domain. Cannulas in the vena cavae were created using COMSOL geometry features. A computational mesh of 500,000 elements was created and solved with the finite element method.

Fluid flow in the blood domain was solved with the Navier-Stokes equations, and coupled to the mechanical properties of the atrial wall to model the expansion and contraction of the right atrial chamber. Convective oxygen transport was coupled to blood flow for modeling oxygen distribution and recirculation. One cardiac cycle was solved to establish initial conditions for the following cardiac cycle, which was used for calculations. Recirculation fraction was computed using the formula (SdO2 - SvO2)/(SrO2 - SvO2) where subscripts d = drainage, r = reinfusion, and v = mixed venous saturations.

The model simulated atrial function appropriately (Fig. 1). Volume (Fig. 2) and pressure curves of the right atrium matched physiologic conditions, and flow patterns reflected atrial contraction and relaxation. Initial application was to model recirculation using two-cannula VV ECMO in the normal configuration (Fig. 3). Future application will include analysis of cardiac output, vena cava flow, and atrial systole/diastole as well as cannula design, configuration, placement and displacement. Optimization of dual-lumen cannula design or novel designs can be evaluated in silico before bench or clinical testing is performed.

Developing Protocols to Decrease Incidence of Air Entrainment in ECMO

Abstract: In 2009 there was a resurgence of interest in adult Extra-Corporeal Membrane Oxygenation (ECMO) secondary to the H1N1 Influenza pandemic. In 2014, The Vanderbilt Heart and Vascular Institute at the Vanderbilt University Medical Center (VUMC) in Nashville, Tennessee recognized the need to assemble an Adult ECMO Team as well as an Adult ECMO Transport Team utilizing our Life Flight ground, helicopter, and fixed-wing fleet. Assembling this multidisciplinary team helped to establish VUMC as the Regional ECMO Center which handles both in and out of hospital consults. VUMC utilizes both Veno-Arterial (VA) and Veno-Venous (VV) ECMO modalities as well as eCPR for patients across the cardiac and respiratory failure spectrums. With the growth of VUMC’s Adult ECMO Team came formal data collection. In 2016, VUMC had a total of 36 adult ECMO patients with 8 in the first quarter. Out of 8 in the first quarter, 1 had air entrained secondary to free-flow IV tubing (any IV tubing attached to the patient or ECMO circuit that is not run via an IV pump). With air entrainment being one of the biggest risks an ECMO patient faces, a need for protocol development and education rollout was identified. A monthly newsletter, “ECMO News”, was initiated with brief bullet points that address common safety issues bedside staff should keep in mind. VUMC also incorporated the new protocol into the “ECMO 101” class curriculum which targets bedside staff across the critical care continuum at VUMC including Life Flight counterparts. Additional education initiatives have been expanded to include other departments (Speech Therapy, Physical Therapy, Respiratory Therapy, Sonographers, provider groups, etc.). Since the rollout of the new protocol and execution of education initiatives, data tracking has shown zero incidence of air entrainment in the VUMC Adult ECMO population, YTD.

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Safety and Efficacy of Left Internal Jugular Bica caval Dual lumen catheter for Extracorporeal Membrane Oxygenation
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Early cases utilized dual cannulation sites typically involving the internal jugular vein with a femoral vein or both of the femoral veins. The use of two cannulation sites increased the risk of complications from cannulation, infection at insertion site and incidence of recirculation. The introduction of a single site access allowed for increased patient mobility, decreased risk of infection and reduced recirculation. We report our experience of four cases in which either a 27 Fr or 31 Fr Avalon cannula was used to cannulate the left internal jugular vein.

In case 1, the patient presented with severe hypoxemic and hypercapnic respiratory failure secondary to ARDS. Patient was initially placed on veno-arterial ECMO due to requirement of significant hemodynamic support. With recovery of the left ventricle (LV), decision was made to transition to a left IJ Avalon catheter, in order to facilitate physical therapy. The right internal jugular vein was inaccessible as it had been previously cannulated. A 31 Fr Avalon catheter was placed under fluoroscopy with confirmation of position with use of TEE. Case 2 was that of a hypoxemic lung transplant patient, who had developed acute rejection of her prior transplant. Patient was placed back on ECMO as a bridge to re-transplant. The right IJ was inaccessible due to prior cannulation and therefore the LJ was accessed. In Case 3, a 36 year old male was involved in a motor vehicle crash, following which he developed ARDS secondary to pulmonary contusion and pneumonia. Due to hemodynamic instability and severe hypoxemia at the time of presentation the patient was placed on veno-arterio-venous ECMO. Following stabilization of hemodynamics the patient was transitioned to veno-venous ECMO via a left IJ 31 Fr Avalon catheter in order to facilitate physical therapy.

Prior cases have demonstrated safety in use of the LJ Avalon cannula in sizes up to 27 Fr. Our case series demonstrates that the LJ can be safely used in sizes as large as 31 Fr when inserted with TEE guidance. Cannula size is primarily determined based upon the ability to meet O2 requirements. Classically the use of body surface area (BSA) x 2.2 has been used to determine flow requirements. With initiation of mobility, cardiac output (CO) must increase to meet demand. Flow should be at least 60% of CO in order to allow for mobility, however this requires continued monitoring. Our group chooses cannula size based on the ability to provide 60–80 ml/kg/min, while simultaneously avoiding a pressure drop of greater than 100 mmHg at the desired flow rate. Prior evaluation of the vasculature can help to identify stricture from prior cannulation or obstruction from thrombus. The diameter of the vein is also taken into consideration when choosing optimal size. We prefer that the vein be 1–3 Fr larger then the cannula. Obstruction of venous flow by a larger catheter likely impairs cerebral venous return and increases risk of developing thrombus caudal to the catheter insertion site. Beside echo can be used daily to assess positioning of the arterial return and to monitor for migration of the IVC port. Migration into the insertion of the hepatic vein can produce a budd-chiari syndrome due to the narrowing and resultant turbulent flow.

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VV ECMO as salvage therapy for ARDS secondary to Malaria
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Introduction: Classically severe malaria affects tropical regions, however with the growth of travel to these endemic regions complicated malaria has become much more common. Falciparum malaria has shown to be the most common cause of severe malaria, however ARDS can also be seen with vivax and ovale. Respiratory failure secondary to malaria is relatively rare with increase predominance seen in those patients with associated cerebral malaria. Despite a reduction in parasite load patients often die secondary to the pulmonary complications of malaria.

Case: 18 year old female presented to the ER with altered mental status. Patient had returned from a trip to Cameroon, following which she developed fevers, chills, malaise and anorexia. Patient was intubated in the ER due to worsening mentation. CT of the head demonstrated diffuse cerebral edema. Blood analysis demonstrated falciparum with parasitemia of 15%, therefore patient started on IV quinine. Patient developed progressive hypoxemia, with CXR demonstrating the development of bilateral alveolar infiltrates. Mean airway pressures progressively rose to greater then 20 with plateau pressures of greater then 30. FiO2/paO2 noted to be 40 with oxygenation index of 37.5. Patient attempted on APRV, sedated and paralyzed. Due to minimal response, proning initiated in conjunction with inhaled epoprostenol. Due to persistent hypoxemia patient placed on VV ECMO with 27 Fr Avalon cannula via R IJ under fluoroscopy and ultrasound guidance. Patient maintained at a flow of 3.5L/min at 3775 rpms. Transition to ECMO allowed for a reduction in driving pressures and FiO2. Patient however demonstrated an progressive increase in necessary O2 support. Significant clotting noted to develop throughout the circuit and the oxygenator. Decision was made to attempt to transition patient to a 31 Fr cannula. Intra operatively patient developed period of asystole, requiring administration of epinephrine and conversion to VAV ECMO. Cannulation was with a 22 Fr catheter to the right femoral vein, 15 Fr catheter to the left femoral artery with distal SFA perfusion catheter and a 15 Fr cannula to the right subclavian vein. The ability to escalate O2 delivery allowed for aggressive diuresis, with improvement in lung compliance and oxygenation. She was decannulated after 15 days on ECMO.

Discussion: The pathophysiology of ARDS in malaria is poorly understood. It is suspected that malarial parasites contain a toxin which is released upon rupture, triggering the release and activation of TNF alpha and IL-1. The cytokines in turn induce the the release of pro inflammatory cytokines IL-8 and IL-6. The resultant endothelial injury causes increased alveolar permeability. The endothelial injury is likely compounded by a reduction in nitric oxide. Nitric oxide production is decreased due to a reduction in L-arginine and an increase in plasma free hemoglobin which functions as a nitric oxide scavenger. The resultant hypoxia can be attenuated and high airway pressures can be avoided by the use of ECMO. In cases of complicated malaria, ECMO should be considered as an appropriate option for management as the underlying etiology is most likely an inflammatory response which will recover with time.

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**ECMO Case Study: Decision Making During Differential Diagnoses and Complications**

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N.M. was a previously healthy 39kg, 9 y.o. African American male. Five days prior to admission, he was tackled playing flag football. He progressed shortly after admission and his first x-ray showed complete whiteout of the left lung and a large mass causing mediastinal shift to the right. He was transferred to our center on a non-rebreather mask. A CT scan of his chest showed a large mediastinal mass affecting the heart and great vessels, a large left pleural effusion, and pleural soft tissue to humeral implants extending throughout the entire right hemithorax. A CT of his abdomen showed multiple masses on his kidneys bilaterally. Hematology/Oncology was consulted and recommended a chest tube insertion for pleural fluid that would aid in diagnoses and relief of shortness of breath. He was diagnosed with T-cell lymphoma and given an emergency dose of chemotherapy but he rapidly deteriorated and was placed on VA ECMO 12 hours after his admission to the PICU. In addition, PICU staff and surgeons were unable to place an orogastric tube due to compression of the esophagus from the tumor.

Cannulation was uneventful. VA bypass was chosen due to the compression of the trachea and the mass effect on the heart function. ECMO flow settled around 3500 L/min providing adequate oxygenation. ECMO day 3, crepitus was felt throughout the abdominal area. An x-ray confirmed the diagnosis of pneumoperitoneum. He was taken to surgery that day for an exploratory laparotomy. The surgeons note was as follows: There was pneumoperitoneum evident specifically in the lesser sac area all the way up to the hiatus. There was bubbly air throughout the upper abdomen with no air within the mesenteric distal of the small bowel. There was no contaminated fluid present either. The stomach was examined and there was no obvious perforation of the stomach nor the duodenum nor colon. The pneumoperitoneum was felt to be a perforation of either a segment of bowel that had sealed versus air that had tracked down from the mediastinum into the abdomen. The abdomen was cleaned, irrigated, and a gastrostomy tube placed. A bronchoscopy on ECMO day 6 showed continued complete obstruction of the left broncsus. Over the next 96 hours, there was significant bleeding from the abdominal wound such that by ECMO day 8, he needed a second venous drainage cannula. A registry search for similarly diagnosed patients revealed only one 15 year old patient who died at 56 hours of ECMO. ECMO day 9, there was concern for compartment syndrome development throughout his abdomen with increase in edema, and girth, as well as a decrease in urine output. Hemo-filtration was considered but after checking bladder pressures which measured 50-60mmhg, surgeons were called to place an abdominal drain. A Tenkoff tube was placed and immediately drained 1200 ml of bloody fluid and then continued draining greater than 200 ml/hr. Cell saver use was discussed and found to be contraindicated in this case. ECMO day 13, N.M was successfully decannulated and all cannula site vessels repaired. He was extubated 7 days after decannulation and now continues his hospital course with radiation and chemotherapy while regaining strength and endurance for the journey ahead.

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**Venoarterial Extracorporeal Life Support in Pediatric Diabetic Patient with Disseminated Mucormycosis**

Renee Devor, MD and Elizabeth Zorn, MD; Phoenix Children’s Hospital

**Introduction:** Mucormycosis has emerged as the third most common invasive fungal infection worldwide over the past two decades, occurring most commonly in immunocompromised hosts. Mucormycosis remains a threat in patients with diabetes mellitus with the majority of invasive infections occurring in those with poor glycemic control. The overall mortality rate remains >50% and nearly 100% in patients with disseminated disease.

**Description:** A 13-year-old male presented with new-onset DKA that was successfully treated with an insulin infusion and intravenous fluids. His anion gap closed but he developed a lactic acidosis, hypoxemia, and required intubation. Chest xray revealed bilateral infiltrates and broad spectrum antibiotics were initiated. He underwent CT head which was negative for cerebral edema, acute intracranial pathology, or sinus disease. He rapidly progressed to septic shock requiring multiple high dose vasoactive infusions and was ultimately cannulated for VA ECLS for hemodynamic instability through the right femoral vein (25F Bio-Medicus) and left femoral artery (17F Bio-Medicus). Bronchial alveolar lavage resulted in the identification of *Mucor* species which prompted treatment with liposomal amphotericin and micafungin.

The patient had multiple infectious complications while on ECLS and required several bedside procedures while fully anticoagulated. At the time of cannulation, he was profoundly vasoconstricted on high doses of vasoactive medications that resulted in the inability to place arterial reperfusion cannula in the lower extremity. The following day, once vasoactives were weaned and he was adequately fluid resuscitated, a 6F arterial reperfusion cannula was placed in the left posterior tibial artery. Despite this, he manifested significant ischemic injury and dry gangrene of the distal left foot. He developed persistent pleural effusions requiring surgical chest tube placement that revealed a large amount of dark brown fluid containing necrotic tissue and *Mucor*. He also had pericardial tamponade physiology necessitating pericardiocenteses with drain placement; black necrotic fluid with *Mucor* was drained from the pericardium. There were no bleeding complications despite full anticoagulation with heparin infusion during all procedures.

He also developed acute renal failure requiring continuous renal replacement therapy. Repeat head imaging showed invasive infection in the frontal and temporal lobes of the brain as well as extensive sinus disease and widespread necrosis of the lungs. After 8 days on VA ECLS, he developed progressive hypoxemia despite full ECLS and ventilator support. Due to the rapid extension of the mucormycosis and the high mortality rates associated with disseminated infection, the family chose to withdraw support.

**Discussion:** Mucormycosis remains a rare infection in the United States but is associated with significant mortality. Our patient illustrates the need to remain vigilant when the course of a common diagnosis, such as DKA, does not proceed as expected. Bedside procedures may be safely performed on patients who are anticoagulated while on ECLS support. Despite support with VA ECLS for septic shock, mucormycosis remains difficult to treat which may have made him an inappropriate candidate for ECLS had the diagnosis been known.

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**ELSO ABSTRACTS**

**Mucormycosis**

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renee Devor</td>
<td>Venoarterial Extracorporeal Life Support in Pediatric Diabetic Patient with Disseminated Mucormycosis</td>
<td>Phoenix Children’s Hospital</td>
</tr>
</tbody>
</table>

**Mucormycosis as a Complication of ECMO Case Study**

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann Diaz et al.</td>
<td>ECMO Case Study: Decision Making During Differential Diagnoses and Complications</td>
<td>Arnold Palmer Medical Center, Orlando, Florida</td>
</tr>
</tbody>
</table>

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Extracorporeal Membrane Oxygenation Characteristics and Outcomes in Adult Down Syndrome Patients

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Introduction: Patients with Down Syndrome (DS) may have multiple medical issues that place them at risk for requiring extracorporeal membrane oxygenation (ECMO). Use of ECMO in pediatric DS patients has been described, but minimal data exist for ECMO use in adults with DS. Goal of this study was to describe the clinical characteristics and to determine if there were differences between those patients that were alive (aDS) versus those that were dead (dDS) at hospital discharge.

Methods: DS patients that were 18 years and older registered in the Extracorporeal Life Support Organization (ELSO) registry from 1983 – 2016 were analyzed. Demographics and ECMO characteristics were recorded.

Results: Total of 21 adult DS were identified. Incidence of ECMO in adult DS was 0.88 per 1000 ECMO procedures. Hospital mortality was 57% (12/21). There were no significant differences between aDS versus dDS for age (24.9 + 4.8 yrs vs. 28.1 + 10.2 yrs), weight (90.7 + 13.0 kg vs. 79.1 + 27.0 kg), gender (4 males vs. 8 males), initial pH (7.18 + 0.19 vs. 7.27 + 0.16), or initial pCO2 (51.7 + 13.9 vs. 45.4 + 19.9), respectively. There were no significant differences between aDS versus dDS in duration of ECMO run (239 + 159 hrs vs. 455 + 570 hrs, respectively), ventilator or ECMO mode, and nitric oxide use. aDS had less incidence of mechanical ventilation (41.7% vs. 0.0%, p < 0.05) and neurologic complications (41.7% vs. 0.0%, p < 0.05) versus dDS. There were no other significant differences in complication rates between the two groups.

Conclusion: Use of ECMO in adult DS population is significantly less compared to the pediatric DS population. Baseline characteristics are not predictive of overall survival. There are minimal differences noted between aDS versus dDS during their ECMO course. Mortality rates are similar to non-DS patients placed on ECMO. ECMO may be a reasonable option for adult DS patients requiring intensive care.

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Case Report: Successful use of pulmonary cryotherapy tracheobronchial thrombus debridement during a pediatric V-V ECMO run.

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This report, to our knowledge, describes the first reported pediatric use of pulmonary cryotherapy for refractory airway obstruction due to tracheobronchial thrombus.

Our patient was a 7 year old girl with a history of Di George Syndrome and Truncus Arteriosus with right aortic arch. Her cardiac palliation included Truncal repair complicated by both homograft and eventual truncal valve insufficiency resulting in repaired truncus anatomy with an 18mm Contegra RV to PA conduit and a 19mm St Jude mechanical truncal valve. She was admitted to our institution with Ossa endocarditis involving her conduit and systemic valves, septic pulmonary emboli with multiple abscesses and severe ARDS. She had progressive hypoxemia requiring Veno-venous ECMO cannulation using a 23mm double lumen Origen cannula. Early in her ECMO course she had significant airway bleeding leading to the development of bilateral obstructing tracheobronchial thrombus that could not be cleared using daily flexible bronchoscopy and mucolytic therapy. Three attempts at rigid bronchoscopy were made, all resulting in airway bleeding and return of obstructing thrombus. Two of these attempts were made with reduced dosing of heparin, heparin being held prior to procedure and with the use of AMICAR. At day 25 of her ECMO course she continued to have complete airway obstruction and resultant complete bilateral lung collapse along with ongoing endocarditis.

In this challenging clinical situation, any chance of survival to operative management of her endocarditis required clearance of the debris from her airways to allow for lung recruitment. Based on adult case reports and series using cryoextraction for obstructing tracheobronchial thrombus, we reached out to our adult interventional cryotherapy colleagues. Using a 3.5 flexible bronchoscope with a cryoprobe through a 5.5 endotracheal tube, the obstructing thrombus was removed in a piecemeal manner in two separate procedural sessions. The first session was clearing the left airways and the second clearing the right airways. This was done in conjunction with a transition to heparin free ECMO using a quadrox oxygenator and Rota Flow pump. She remained off heparin for 5 days without complication. With her airway successfully debried lung recruitment was achieved with gradually improving ventilator mechanics, gas exchange and chest x-ray imaging until she was weaned from ECMO 5 days after completion of her cryointervention on ECMO day 30.

This case demonstrates the potential for cryoextraction to relieve persistent completely obstructing tracheobronchial thrombus in a pediatric patient. This therapy allowed our patient to wean from ECMO giving her a chance at recovery in a challenging clinical scenario. Cryoextraction has the potential to provide airway clearance with a decreased risk of further bleeding and injury in pediatric patients with tracheobronchial thrombus. There may also be utility in other causes of obstructing pediatric tracheobronchial disease.
Using Anti-Xa levels to monitor anti-coagulation using UFH on ECMO: Are you killing your patient?
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Introduction: Unfractionated Heparin (UFH) is a mainstay of anticoagulation therapy for patients receiving Extracorporeal Membrane Oxygenation (ECMO). Despite its long history of use the optimal value to measure its activity remains unclear. The monitoring of anti-factor Xa levels has become more common due increasing availability and reduced costs as well as some research showing improved times to therapeutic anticoagulation when compared to the more traditional partial thromboplastin time (PTT) or activated clotting time (ACT) tests. The aim of this study is to investigate the relationship between PTT and anti-Xa lab values for monitoring UFH in patients receiving ECMO and to determine if currently accepted therapeutic PTT and anti-Xa levels are concordant in ECMO patients.

Method: Single center retrospective chart review comparing paired anti-Xa and PTT values for patients receiving ECMO therapy and UFH. Paired values were considered lab values drawn at the same time. The primary objective of the study was to assess frequency of therapeutic concordance in paired anti-Xa and PTT values. Therapeutic concordance was defined as both PTT and anti-Xa below, within, or above defined therapeutic range. Secondary objectives were to, determine heparin dose and time to reach therapeutic PTT and anti-Xa and assess for presence of known lab values that interfere with anti-Xa and PTT tests.

Results: 16 out of 25 patients met inclusion criteria for this study. In this group there were 124 paired anti-Xa and PTT samples. Only 33 (27%) of the paired values were concordant compared to 91 (73%) that were discordant. R² value was 0.27, showing a very weak correlation between PTT and anti-Xa values. Most commonly when values were discordant we found therapeutic PTT and sub-therapeutic Anti-Xa. Time to reach therapeutic PTT was 9.51 hrs ± 8.41 hrs on an average UFH dose of 13.6 U/kg ± 6.20, while time to therapeutic anti-Xa was 35.8 hrs ± 27.90 hrs on an average UFH dose of 18 U/kg ± 4.75 U/Kg. 13 (81.25%) of the 16 patients had elevation of known lab values that cause false interpretation of anti-Xa and PTT with hemolysis, as evidenced by an elevated serum lactate dehydrogenase (LDH), being the primary cause.

Conclusion: In our population we experienced a high level of discordance between anti-Xa and PTT lab results. There are numerous factors which may potentially be responsible for this finding. Anti-Xa testing is done with a chromogenic assay which could be affected by drugs such as methylene blue or vitamin B12 as well as hyperbilirubinemia, hyperlipidemia and hemolysis all of which were common in our population. In particular, elevated serum LDH levels were present in 56% of the patients and could potentially lead to a falsely lowered anti-Xa level. Research has also shown that patients on mechanical circulatory support frequently have lowered levels of multiple clotting factors which will affect coagulation but may not be reflected in anti-Xa levels. Furthermore, we found that, contrary to published research, PTT reached therapeutic levels 26.29 hours before anti-Xa and with a dose of UFH 4.4 units/kg lower than that needed to achieve a therapeutic anti-Xa. While the anti-Xa assay may be gaining popularity for monitoring UFH therapy, caution should be used when implementing its use in ECMO patients as the assay has some unique limitations that become problematic in this complex population.

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Impella Device as a Reliable Strategy to Unload the Left Ventricle During Peripheral Venoarterial Extracorporeal Membrane Oxygenation Support: The Massachusetts General Hospital Experience
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Background: Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) stabilizes patients in cardiogenic shock. While VA ECMO therapy improves hemodynamics in cardiogenic shock, an increased afterload and lack of ventricular ejection can cause left ventricular distension (LV). VA-ECMO alone cannot decompress the distended LV. We present our experience utilizing the Impella-2.5™ pump to vent the LV during VA-ECMO.

Methods: Patients cannulated for VA ECMO with placement of an Impella™ as an LV vent were identified through our ECMO database from 2015 to May 2017. We collected demographic, survival, clinical, echocardiographic, and operative details.

Results: Fifty-nine patients were placed on VA-ECMO from 2015 to January 2017. Twelve patients had concurrent placement of an Impella-2.5™. VA-ECMO with Impella-2.5™ indications included: STEMI (n = 6), myocarditis (n = 4), mechanical structural complication (n = 1), and iatrogenic catheterization complication (n = 1). Impella-2.5™ was most common (n = 8), followed by Impella-CP™ (n = 4). In-hospital survival was 58% (n = 7), compared to an institutional survival average for VA-ECMO patients of 42.6%. Survivors were less likely to have presented with STEMI and to have undergone PCI. Survivors were less likely to have experienced hemolysis as a complication as measured by LDH. Survivors were bridged to recovery (n = 5), heart transplantation (n = 1), and durable LVAD (n = 1).

A trend towards improvement in LV function after ECMO and Impella therapy was noted on echocardiography in patients who survived. Pre-cannulation LV function on echocardiography did not appear to play a role in survival.

Conclusion: Impella™ with VA-ECMO permits LV unloading and a greater than 50% hospital survival. We observed greater survival advantage in patients presenting in cardiogenic shock from myocarditis or mechanical complications of STEMI. Impella™ patients who died tended to have echocardiographic evidence of LV dilation during VA ECMO/Impella therapy; while survivors had a reduction in cavity size and improved systolic function after device removal.

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**In vitro** comparison of two neonatal ECMO circuits using a roller or centrifugal pump with three different in-line hemoconcentrators for maintaining hemodynamic energy delivery to the patient

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**ABSTRACT**

**Objective:** To compare three different hemoconcentrators (Hemocor HPH 400, Mini and Junior) with two different neonatal extra-corporeal membrane oxygenation (ECMO) circuits using a roller or a centrifugal pump at different pseudo-patient pressures and flow rates in terms of hemodynamic properties. Total hemodynamic energy (THE) generated and transmitted to the patient is used as a measure of organ perfusion and is calculated with energy equivalent pressure (EEP) used to quantify pulsatility.

**Methods:** The circuits used a 300-mL soft-shell reservoir as a pseudo-patient approximating the blood volume of a 3kg neonate and a Quadriox iD Pediatric oxygenator with three different in-line hemoconcentrators (Hemocor HPH 400, Mini, and Junior). One circuit used a Maquet H20 roller pump and another circuit used a Maquet RotaFlow centrifugal pump. The circuit was primed with lactated Ringer’s solution followed by heparinized packed red blood cells (hematocrit of 40%). The pseudo-patient’s pressure was manually maintained at 40, 60 or 80 mmHg and the flow rate was maintained at 200, 400, or 600 mL/min with a circuit temperature of 36°C. Pressure and flow data was recorded using a custom-made data acquisition device. Mean pressures, diverted blood flow, pressure drops, and total hemodynamic energy were calculated for each experimental condition.

**Results:** The Hemocor HPH Junior hemoconcentrator added the highest resistance to the circuit. The Hemocor HPH Junior provided the highest circuit pressures, lowest diverted blood flow, highest pressure drop across the circuit, and highest THE generated by the pump. The Hemocor HPH 400 added the least resistance to the circuit, providing the lowest circuit pressures, more diverted flow, lowest pressure drop, and the lowest THE generated by the pump. The amount of THE transmitted to the patient was the similar with all three hemoconcentrators. The roller pump and centrifugal pump performed similarly for all hemodynamic properties with all experimental conditions.

**Conclusion:** The three hemoconcentrators added a different amount of resistance into the ECMO circuit. The Hemocor HPH Junior added the most resistance as seen in higher circuit pressure, less diverted flow, greater pressure drop across the circuit, and more total hemodynamic energy (THE) generated by the pump. The Hemocor HPH 400 added the least amount of resistance as seen in the lowest circuit pressures, lowest pressure drop across the circuit, more diverted flow, and less THE generated by the pump. While the three hemoconcentrators performed differently in terms of hemodynamic properties throughout the circuit, the THE transmitted to the patient was similar for all three hemoconcentrators due to the consistent pseudo-patient’s pressure that was manually maintained for each trial. While the THE delivered to the patient indicates similar perfusion for these patients with any of the three hemoconcentrators, the differences in added resistance to the circuit may impact the decision of which hemoconcentrator is used.

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Neonatal Extracorporeal Membrane Oxygenation Sedation Practices: the four year experience

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Introduction: We previously described neonatal sedation use over a 2 year period in a quaternary pediatric institution. Clinical variance was vast and sedation administration inconsistently applied. Following that analysis, the Newborn/Infant Intensive Care Unit (N/IICU) instituted several interventions including use of a unit wide sedation pathway including the state behavioral scale (SBS), and dexmedetomidine for neonatal extracorporeal membrane oxygenation (ECMO) patients with the goal of reducing overall sedation use, specifically benzodiazepines and barbiturates.

Methods: A 4 year retrospective chart review was performed of all ECMO patients in the N/IICU in 2 cohorts. Cohort 1 consisted of patients on ECMO from 1/1/12 to 1/1/14. Cohort 2 included patients on ECMO from 1/2/14 to 1/1/16. All patients on ECMO support for at least 24 hours were included. Data collected from medical records included demographic information, type of sedation utilized (continuous infusion, scheduled intermittent, and pro re nata [PRN]) and daily dose of sedation while on ECMO. Pain scores were recorded for both cohorts. SBS data was collected for cohort 2 starting 5/1/15. Opioids were converted to intravenous morphine equivalents and benzodiazepines were converted to intravenous midazolam equivalents. Patient comparative groups were patients with surgical diagnoses versus non-surgical diagnoses and patients with ECMO duration ≤14 days and those ≥15 days. The cohorts were compared to see if interventions initiated after 1/1/14 changed sedation practices.

Results: Fifty-one neonates required ECMO support during the first cohort and 38 patients in the second cohort. The most commonly used continuous medication infusions (CMI) remained the same including morphine, midazolam, and hydromorphone with the addition of dexmedetomidine in February 2014 for cohort 2. Dexmedetomidine was used in 8 patients, 4 non-surgical and 4 surgical patients. A loading dose was given for 7 patients with the same dosing as non-ECMO patients. No bradycardia was noted. It was often added to temporize escalating doses of opioid and benzodiazepine infusions. The patients who received dexmedetomidine received 25% less pentobarbital than those who did not and had similar ECMO duration. It was utilized for 45 to 219 hours while on ECMO, and 7 of the 8 patients continued the infusion after ECMO. Cohort 1 had 26 non-surgical patients, 25 surgical patients, 35 patients with ECMO duration ≤14 days, 16 patients’ ≥15 days. Cohort 2 had 15 non-surgical patients, 23 surgical patients, 18 patients with ECMO duration ≤14 days and 20 patients ≥15 days. The unit sedation pathway and SBS scoring began in May 2015 therefore only17 patients in cohort 2 had SBS scores available. SBS scores for those patients ranged from -3 to +2, with 57% of scores being -1 to -3, with goal most often set at -1. Pain scores in both cohorts were never > 2, with range 0–10. Cohort 2 had fewer total patients, but 51% (n=20), had an ECMO duration ≥15 days compared to only 31% in cohort 1. In cohort 2, non-surgical patients had increased doses of both morphine and midazolam equivalents on day 1, 7, and 14, by up to 50% compared to surgical patients. Nearly all patients in cohort 2 had lower median doses of morphine and midazolam equivalents on day 1, 7 and 14 compared to cohort 1. In cohort 1, 96% of patients received benzodiazepines by ECMO day 1. Cohort 2 had only 71% benzo diazepine use on ECMO day 1.

Conclusions: Cohort 2 had an increased number of surgical patients with greater length of ECMO run and should be noted when comparing sedation use between cohorts. The sedation pathway commenced May 2015 and is still being utilized. Dexmedetomidine was used in 8 patients and was most often used as an adjunct therapy to opioid and benzodiazepines. Dexmedetomidine reduced barbiturate doses by 25% and may have helped reduce escalations of benzodiazepine or opioid infusions, though further analysis is needed.

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Hematopoietic Stem Cell Transplantation on Veno- Arterial ECMO in a Pediatric Patient with Aplastic Anemia and Septic Shock

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Introduction: Historically, patients prior to or after bone marrow transplant have been poor ECMO candidates due to high mortality rates. Favorable indicators for ECMO for those patients requiring hematopoietic stem cell transplantation (HSCT) remain unclear due to limited outcome data, with many considering allogeneic stem cell transplant an absolute contraindication to ECMO. To our knowledge, the only successful documented case of ECMO prior to and during HSCT is that of a 15 month old with Wiskott-Aldrich Syndrome (WAS). We report the case of a 2 year old female with severe aplastic anemia and Escherichia coli septic shock necessitating HSCT on VA-ECMO.

Case Report: This 2 year-old female with a confirmed diagnosis of severe aplastic anemia was admitted to begin a preparative regimen with fludarabine, cyclophosphamide, and equine antithymocyte globulin for HSCT with an HLA-matched sibling. On Day -2 of her HSCT and hospital day (HD) #6, she developed significant hemodynamic instability with Escherichia coli septic shock necessitating transfer to the pediatric intensive care unit, aggressive volume resuscitation, mechanical ventilation, and vasopressor support with high dose epinephrine and norepinephrine. Milrinone was initiated for moderately decreased ventricular function. She had a brief episode of cardiac arrest with ROSC after 2 minutes of resuscitation. At this junction ECMO candidacy was discussed. Given the prognosis of aplastic anemia without HSCT, the potential reversibility of Escherichia coli sepsis, and previous reported success with HSCT on ECMO in a WAS patient with E. coli septic shock, ECMO support was offered.

She was cannulated with a 14 French arterial cannula in the right carotid artery and a 16 French venous cannula in the right internal jugular vein on HD#7. Continuous Renal Replacement Therapy (CRRT) was initiated on HD#7 for fluid overload. She underwent infusion of ABO compatible, bone marrow harvested cells with a Total Nucleated Cell Count of 9.51 × 10^8/kg from her HLA-matched sibling on HD#8 via post oxygenator port on ECMO. CRRT was held for 4 hours after the HSCT then resumed. Within 48 hours of VA cannulation she was weaned off norepinephrine and maintained on low-dose infusions of epinephrine and milrinone. Patient underwent atrial septostomy and placement of 15 French femoral venous catheter HD#9 for left atrial hypertension and left ventricular dysfunction. She was maintained on VA ECMO for 6 days with improvement in cardiopulmonary function and was successfully decannulated on HD#13. On Day +11 following HSCT, peripheral blood chimerism testing demonstrates mixed chimerism, although early to determine engraftment. At the time of this report, she remains on mechanical ventilation, CRRT, and daily granulocyte infusions. This case supports that the decision to place such patients on ECMO be individualized to their overall disease process, and that HSCT is not alone a contraindication to ECMO.

References:

Managing the Hypercoagulable ECLS Patient: An Opportunity for Improvement to the Registry

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Abstract

Background: Although the vast majority of patients managed with ECLS are treated with anticoagulants, some degree of circuit thrombus formation nonetheless is common. Fortunately, catastrophic circuit thrombosis is infrequent while anticoagulated. We report a patient who ultimately required a combination of high dose heparin, clopidogrel, and warfarin to keep her circuit from thrombosing. Review of the literature, ELSO Registry, and the ELSO Red Book revealed a disappointing lack of data to help guide therapy.

Case: A 19-yo woman without any history of hypercoagulability presented to an outside hospital with a 2-week respiratory illness. She was intubated and transferred to our facility due to refractory hypoxemia. VV-ECMO was initiated via a fem-fem approach which was then changed to a 31 Fr dual-lumen IJ cannula on Day 2. Heparin was titrated to an anti-Xa level of 0.3–0.5. Antithrombin levels were monitored and replaced as needed. Thromboelastography (TEG) was obtained daily. She required a circuit change on Day 14 due to increasing thrombus formation; heparin was continued. On Day 29 her circuit pressures abruptly rose and flows fell necessitating an emergency circuit change. Her heparin goal was changed to 0.5–0.7 and on Day 32 aspirin 81 mg daily was added. On Day 35 her circuit again abruptly clotted requiring another emergency circuit change. Heparin was stopped and argatroban begun. Two days later on Day 37 her circuit again abruptly thrombosed requiring another emergency circuit change. Argatroban was stopped and heparin resumed with goal 0.8–1. Three days later on Day 40 increasing clot required another circuit change. Heparin was added to her heparin and clopidogrel. On Day 64 her circuit was electively changed to increasing thrombus. On Day 84 she was successfully decannulated without requiring any more circuit changes. She was eventually weaned from the ventilator and discharged home on nasal cannula oxygen after a 4½ month hospitalization.

Literature Review: The ELSO Red Book 4th Edition (the one available at the time), as well as the current 5th edition, offers no guidance regarding managing patients who fail standard anticoagulation (as opposed to management suggestions for patients with contraindications to heparin, such as HIT). A professional literature search by a reference librarian also failed to find relevant data. The ELSO Registry does not track anticoagulation modalities, so it also failed to provide guidance in this patient’s management.

Conclusion: While rare, occasional patients are markedly hypercoagulable necessitating creative anticoagulation regimens. The lack of data on this complex patient population makes management even more challenging.

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The patient was a 19-year-old woman without any history of hypercoagulability pre-intubation. She was eventually weaned from the ventilator and discharged. However, her circuit was electively changed due to increasing thrombus. On Day 49, a thrombus in the pump required another emergency circuit change. Aspirin was stopped and clopidogrel 75 mg daily begun. Heparin was stopped and argatroban begun. Two days later, another emergency circuit change was needed. Her heparin goal was changed to 0.5–0.7 and on Day 32, aspirin 81 mg daily was added. On Day 29, her circuit pressures abruptly rose and flows fell necessitating an emergency circuit change. Her heparin goal was continued. On Day 35, her circuit again abruptly clotted requiring another emergency circuit change. At this point, heparin was titrated to an anti-Xa level of 0.3–0.5. Antithrombin levels were monitored and replaced as needed. Overall, the patient’s management still was challenging, necessitating creative anticoagulation regimens. The lack of data on this practice makes evidence-based management particularly challenging. The ELSO Registry does not track anticoagulant use, so it also fails to provide guidance in this patient’s case.

Case:

A 19-yo woman without any history of hypercoagulability presented intubated and transferred to our facility due to refractory hypoxemia. Extracorporeal membrane oxygenation (ECMO) was initiated via a fem-fem approach which was then changed to a fem-veno approach. Her heparin goal was set to achieve an anti-Xa level of 0.3–0.5. Antithrombin levels were monitored and replaced as needed. The patient’s management still was challenging, necessitating creative anticoagulation regimens. The lack of data on this practice makes evidence-based management particularly challenging. The ELSO Registry does not track anticoagulant use, so it also fails to provide guidance in this patient’s case.

Methods:

A 21-question online survey was developed and disseminated to the American Pediatric Surgical Association (APSA) membership. Participant responses were summarized as counts and percentages. The goal of this study was to investigate individual surgeon approaches towards ECMO cannulations in children.

Results:

There were 252 APSA members who participated in this study for a response rate of 21%, with 225 (89.3%) performing ECMO. Sixty respondents (28.3%) reported using neck vessels exclusively for cannulation regardless of age or weight of the patient. After neck cannulation, 13 (6.6%) repaired the carotid artery for all patients, and 21 (10.7%) repaired only for children older than 5 years. Of those performing femoral cannulation, 56 (26.4%) would perform at 5 years or older and 66 (31.1%) at 12 years. The most common challenge for femoral cannulation was the need for distal perfusion (n=119; 59.8%). Assistance from vascular surgery was requested by 32 (16.4%) for distal perfusion catheter placement, and by 79 (40.5%) for decannulation. Regarding femoral cannulation, lack of training was more likely to be a challenge if performing <5 cannulations per year (25.2% vs 12.5%; p=0.03). Surgeons with <10 years of experience were more likely to consult vascular surgery compared to those with >10 years of experience (18.5% vs 8%; p=0.03).

Conclusion:

Considerable variation exists in individual surgeon cannulation practices in pediatric ECMO, in particular in the management of school age and adolescent VA ECMO. Mixed approaches across several ECMO management case study questions indicate the need for evidence-based clinical studies and clinical practice guidelines.

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Evaluating the Utility of the “Late ECMO Repair”: A Congenital Diaphragmatic Hernia Study Group Investigation

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PURPOSE: Optimal timing of congenital diaphragmatic hernia (CDH) repair in patients requiring extracorporeal membrane oxygenation (ECMO) remains controversial. The “late ECMO repair” is an approach where the patient, once deemed stable for decannulation, is repaired while still on ECMO to enable expeditious return to ECMO if surgery induces instability. The goal of this study was to investigate the potential benefit of this approach by evaluating the rate of return to ECMO after repair.

METHODS: The CDH Study Group database was used to analyze CDH patients requiring ECMO support. The primary outcome was return to ECMO within 72 hours of CDH repair among those repaired following ECMO decannulation (“post-ECMO” patients). Secondary outcomes were death within 72 hours of repair and cumulative death and return to ECMO rate.

RESULTS: A total of 668 patients were repaired post-ECMO decannulation. Six patients (0.9%) in the post-ECMO group required return to ECMO within 72 hours of surgery and a total of 19 (2.8%) died or returned to ECMO within 72 hours of surgery. Deaths were a late event but return to ECMO occurred earlier (figure 1). When looking at all patients who were decannulated without repair on ECMO (including those who were never repaired) it can be seen that the trend in patients returning to ECMO early after decannulation is similar among those who did and did not undergo repair (figure 2).

CONCLUSION: The rate of return to ECMO or death following CDH repair is extremely low and does not justify the risks inherent to “on-ECMO” repair. Patients deemed stable to come off ECMO should proceed with decannulation prior to repair.

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Certification in ECLS for a Successful ECMO Program

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Introduction: Extracorporeal membrane oxygenation (ECMO) is a complex and multidisciplinary therapy that demands the teamwork to acquire and maintain the knowledge and skills necessary to treat the critically ill patient.

Objective: To describe the evolution of our ECMO Certification program, in which we used a hybrid education model to ensure our students acquire theoretical and practical knowledge on ECLS according to all ELSO Guidelines.

Methods: ECMO certification in Mexico began in 2012 with a course based on all the ELSO guidelines (center & training, patient care practice and special topics).

This certification has the institutional support of Hospital CMAE Department of Research and Education and is endorsed by Universidad de Monterrey. It targets physicians, perfusionists, nurses and paramedics. The course was an on-site program that met for one full day a week, for 3 months. It included a combination of didactic instruction, high-fidelity simulation and animal lab sessions (maximum of 8 students per session) and bedside training.

To allow for growth of our center we needed to train more staff so a second certification course was designed similar to the first one but was extended to more students and in two different locations at the same time through live video conferences. The hands on training took place in both locations (Monterrey and Mexico City).

The third certification program is currently up and running and was designed to reach a broader group in four cities in Mexico and other Latin American countries using a blended learning model (online and on-site). It consists of 64 didactic online sessions with pre-recorded video lectures in an online education platform, in which students actively participate in online discussions, submit assignments and take section tests. Afterwards students will participate in an on-site, hands-on 4-day training program that includes wet labs, high-fidelity simulation, animal-lab sessions and bedside training. Upon completion students will take an oral and written evaluation.

Results: In five years we have successfully trained 60 staff members including physicians (neonatologists, pediatric and adult critical care specialists, CV and pediatric surgeons, anesthesiologists, cardiologists), perfusionists, nurses and paramedics. Currently we have 63 students enrolled. During this process, two more centers were opened, which now provide ECMO treatment in three cities in Mexico and our center was awarded the ELSO Pathway to Excellence Award - Silver Level in 2016.

Conclusion: It is important to design an ECLS certification program based on all the ELSO Guidelines to effectively train the team, leading to a successful ECMO Center.

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Implementation of multidisciplinary ECMO team improves outcomes in high volume adult ECMO program.

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Use of extracorporeal membrane oxygenation (ECMO) in the adult population has increased recently across the world following pandemics of H1N1 in 2009–10. We have observed a similar trend in the use of ECMO for the adult population in UCLA Medical Center. In our hospital, overall ECMO utilization in adults increased from 15–20 cases per year before 2010 to 30–50 cases per year in following five years. However, in addition to increasing number of ECMO cases we have observed an increase in mortality, especially in patients supported with VA-ECMO for heart failure. While average survival to hospital discharge in this population was 38% in 2004–2012, we observed a sharp decline in survival in following years with only 15% of patients surviving to discharge in 2015.

In October of 2015 multidisciplinary task force was established to review and improve ECMO practice. Multidisciplinary team included representatives from cardiac surgery, cardiology, critical care and perfusion services. Work of task force was divided into three stages. Stage I included a review of published literature and internal data to developed criteria for ECMO initiation. Stage I resulted in the development of three-tier risk assessment system for candidacy for ECMO therapy. Stage II included the development of multidisciplinary ECMO/shock team that consisted from representative of cardiac surgery, perfusion service, cardiology and critical care. Additionally, in stage II, we have developed centralized activation system and ECMO consult and initiation algorithms based on previously developed criteria. In stage III we have focused on education of staff in key areas of the hospital: emergency department, intensive care units, cath labs and operating rooms. Following implementation of ECMO/shock team, in 2016 we have used VA-ECMO to support 48 patients for variety of indication: postcardiotomy heart failure – 19%, acute cardiogenic shock – 21%, ECPR – 23%, right ventricular failure – 10%, primary graft dysfunction – 17%, end-stage heart failure – 4%, acute respiratory failure – 2% and periprocedural support – 2%. Overall 29 patients (60%) were successfully decannulated from ECMO and 24 patients (50%) survived to the hospital discharge.

In our experience, implementation of multidisciplinary ECMO/shock team with structured activation mechanism, and algorithm-driven VA-ECMO initiation improves survival to hospital discharge in adult patients.

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Creating and Managing an ECMO Program Without a Perfusionist Team – The RN/RT Model

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Introduction: The city of Seattle is home to the University of Washington Medicine Health System. This includes four hospitals and a series of community clinics and specialty surgery centers. Two of the four hospitals in the system are the University of Washington Medical Center and Harborview Medical Center. The University of Washington Medical Center has had an ECMO program for many years as they are a cardiac surgery and transplant center and thus have a robust Perfusion department. Harborview Medical Center is a county owned hospital that proudly offers world class care to patients from all walks of life. With over 17,000 admissions annually, we provide specialty care in nearly every area of medicine and we are a world-renowned Level 1 adult and pediatric trauma and burn center. The University of Washington Medical Center and Harborview Medical Center treat vastly different populations and do not share specialty services so there is no onsite perfusion available at Harborview. Additionally, we are the only designated Level I adult and pediatric trauma and burn center in the WAMI region which includes Washington, Alaska, Montana and Idaho.

Methods: In order to bring ECMO to this unique population, we created an ECLS service and trained a group of RNs and RTs to operate the pumps, prime the circuits, assist with cannulation and manage the daily operations of each ECMO run. We ensure that there are a sufficient number of specialists available on each shift to initiate and run as many ECMO patients as our equipment allows. A multidisciplinary group of providers works together to manage the patients and that collaboration provides the patients with safe and effective care.

Results: Our program has been in place since April 2016. To date we have treated 16 patients and have expanded our indications and capabilities. We have treated 14 patients with a Veno-Venous (VV) configuration, 1 patient with a Veno-Arterial (VA) configuration and 1 patient with VA initially who then transitioned to VV. To date we have a 68.75% survival to hospital discharge rate, VA (100%) and VV (64%). All of our survivors have had a full neurological recovery.

Discussion: Harborview has had good initial patient outcomes while instituting a new ECLS service with nursing and respiratory therapy specialists. The absence of a perfusion team has not been an issue with thoughtful scheduling and sufficient training. We conduct intensive case reviews after each patient run to identify problems early and improve ongoing care.

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VA-ECMO for Post-Cardiomyopathy Cardiogenic Shock: The Oklahoma ECMO Network Experience

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Background: Post-cardiomyopathy cardiogenic shock (PCCS) is a condition that can affect as many as 2–6% of patients whom undergo routine valvular or revascularization surgical procedures.1 The Oklahoma ECMO Network (OEN) provides a regional support service for patients unable to wean from cardiopulmonary bypass (CPB) or who develop post-operative cardiogenic shock refractory to inotropes and vasopressors. This group of patients is highly susceptible to the development of multi-system organ failure with progression to death without intervention with some form of acute mechanical circulatory support (MCS).2 This observational study retrospectively analyzes the outcomes of patients receiving VA-ECMO as salvage therapy for PCSs. Patients were all treated with acute MCS within one centralized facility in Oklahoma City, OK, but were referred from multiple other facilities within the state. The OEN team will deploy with an ECMO physician, coordinator, and a perfusionist to either assist the referring surgeon with transition from CPB to VA-ECMO, or to peripherally cannulate for VA-ECMO and then transfer back to the central facility.

Methods: The data was obtained via retrospective chart review of all patients admitted at INTEGRIS Baptist Medical Center between September 2014 and July 2017 who received acute MCS for PCSs either due to failure to wean from CPB or refractory to use of intra-aortic balloon pump and maximal inotropic support following cardiac surgery in the immediate post-operative period.

Results: A total of 30 patients met inclusion criteria. Ages ranged from 15–77 years (57.3 ± 15.9) with male predominance (n = 25, 83.3%). Of the patients receiving acute MCS therapy 27 (90%) received VA-ECMO, and of these 23 (85%) received peripheral cannulation and 4 (15%) received central cannulation. The remaining 3 patients received short-term VAD (BiVAD with oxygenator = 2, BiVAD = 1). A total of 10 patients (33.3%) were accepted after cardiac arrest requiring CPR. The most common complications noted in our cohort were as follows: gastrointestinal bleeding (n = 3, 10%), major neurologic injury (n = 4, 16.7%), cardiac tamponade requiring surgical exploration (n = 8, 26.7%), and acute kidney injury (AKI) requiring continuous renal replacement therapy (CRRT) (n = 17, 56.7%). Total number of patients weaned from acute MCS was 15 (50%) with 13 (43.3%) surviving to discharge.

Conclusion: Acute MCS for the support of PCSs is a useful tool that can lead to the survival of a significant number of patients who would likely otherwise not survive their acute illness. Our data supports this statement, and is in line with other studies reporting acute MCS use in PCSs.2 Very reasonable survival outcomes have been achieved in this cohort of patients, despite very nonselective patient acceptance (evidenced by the large proportion of patients with multi-organ dysfunction and pre-MCS cardiac arrest). We believe our model of a mobile ECMO team that provides acute MCS for a large geographical region can allow the acceptance of higher risk patients while still maintaining good clinical outcomes.

References:

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Indications for extracorporeal life support in congenital diaphragmatic hernia: What do our guidelines say?
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Objective: Standardized care has the potential to improve outcomes in congenital diaphragmatic hernia (CDH). Extracorporeal life support (ECLS) indication variability between centers is unknown. Our objective was to identify North American (NA) centers with a written CDH clinical practice guideline (CPG) and assess the indications for ECLS among CPGs.

Methods: NA members of the CDHSG and Pediatric Surgical Research Collaborative were solicited via email to submit their CDH CPG. Standardized variables were created for CPG elements, and CPGs were screened by surgeons, with a 10% blinded second audit to ensure consistent abstraction. ECLS indication variables assessed included oxygenation index, hypoxia, ventilator settings, and acidosis. Cardiovascular and echocardiographic indications were also assessed. Descriptive analyses including measures of variation were performed.

Results: Sixty-eight centers were solicited with 40 responses (59%). Of these, 29 (73%) had a CDH CPG; 27 CPGs were obtained for review. Concordance between screeners was 95.0%. ECLS indications were discussed in 25 CPGs (93%). Hypoxia, as assessed by oxygen saturation, was an indication in 67%, with a saturation <85% the most common cutoff (range: 70%-90%). Oxygenation index (OI) was used in 59% of CPGs, with an OI>40 as the most common cutoff (range: 15–40, significant variability regarding duration). Acidosis was an indication in 48%, with pH<7.2 the most common cutoff (range: 7.15–7.25). Ventilator indications included mean airway pressures and peak inspiratory pressures, though many noted “failure” of conventional ventilation in some fashion. Fifty-nine percent identified “hypotension” or “hemodynamic instability” as clear indications, though the specific definitions varied. Only 19% discussed an echocardiographic indication such as poor right ventricular function or ventricular failure.

Conclusions: Our synthesis provides a representative description of standard CPGs from centers caring for infants with CDH. At least 1/3 of centers have no CPG and, among those who do, content variability is high. While ECLS indications are commonly included, the specific indications vary. These data identify important targets for a consensus approach around ECLS support in CDH and progression toward multi-institutional CDH management standardization in NA.

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Aiming to Reduce Errors: Teaching Crisis Resource Management Skills during ECMO Simulation
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Introduction: Simulation education is used for educational opportunities in Extracorporeal Life Support (ECMO) programs for both initial and continuing education. It has been described for physician, nursing and specialist groups. Many ECMO programs use simulation for competency verification or for introduction of new skill sets. We describe the use of simulation to teach crisis resource management (CRM) skills at Children’s Healthcare of Atlanta’s ECMO Program.

Crisis Resource Management skills are skills that focus on how the team works together during highly stressful events. Developed in the airline industry in the 70’s, the skill set was successfully incorporated into anesthesiology in the operating room in the 1990s by Dr. Gaba. As research demonstrated that most medical errors arose due to communication errors, more emphasis has been placed on teaching and incorporating these concepts into highly stressful clinical areas. CRM encompasses many different principles, however Children’s has pinpointed five Key Principles: Effective Communication, Call for Help/Know your Resources, Teamwork and Role Clarity, Flattened Hierarchy and Global Assessment.

Discussion: In 2017, as part of the bi-annual Simulation education offerings, the objectives were developed with full incorporation of CRM skills. CRM was first introduced in a didactic forum at our quarterly ECMO Inservice, which was mandatory for every ECMO Specialist. This was then followed with Simulation. An anonymous pre-and post-survey was completed by every attendee of the Simulation session, (n=37).

The scenarios were based on the introduction of a new ECMO pump platform. While the Specialists had been introduced to the pump briefly, most did not have immediate recall of how to read the alarms, interact with the touchscreen or the pump head itself. The objectives were to reinforce using CRM principles during the scenarios.

Results: Determination of the effectiveness of simulation can be difficult as it involves the self-confidence of the learner and how competent they feel in a simulated environment; as well as determining whether there is improvement in skills and in patient outcomes. The pre- and post-surveys revealed that most Specialists were most concerned about communication (30%), resources (26%) and calling for help (29%). Post surveys found that concerns over communication had fallen to 26%, resources to 22% while calling for help increased to 31%. Additionally, all team members felt that they had increased confidence in communicating with team members and in the need to call for help, even though there was increased concern over calling for help.

Conclusion: We continue to emphasize circuitry emergency skills in water drills sessions, where timing and repetition of skills is done to improve competence and validate performance. Simulation offers an environment to test those previously validated skills, while incorporating realism of consequence of action, and most importantly, emphasizing Crisis Recourse Management skills. The inclusion of CRM in our ECMO program has increased the knowledge of these concepts for the ECMO Specialist and will hopefully translate to better performance during stressful events at the ECMO bedside. Future ECMO simulations will incorporate multi-disciplinary personnel into the practice of Crisis Resource Management skills.

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“Use of venovenous ECMO in patients with Blastomycosis pneumonia: cases and considerations”
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A previously published small case series of patients with ARDS secondary to pulmonary Blastomycosis infection successfully treated with venovenous ECMO suggests that these patients may benefit from aggressive extracorporeal support and lung rest (Bednarzyk, et al, 2015), much in the same way that ARDS from other causes responds. We will report on two patients treated with venovenous ECMO for Blastomycosis pulmonary infection, both of whom succumbed to their illness. While cavitating fungal infection and presence of an opportunistic infection are not contraindications to application of venovenous ECMO, we believe that many questions are raised in these cases.

Patient #1, a 32-year old male, presented to our emergency department with complaints of fever, productive cough, shortness of breath and malaise. Of note, he reported chronic cough for the previous 3–4 months. His medical history was notable for poorly controlled diabetes, managed with insulin, but otherwise he was considered in good health. He required intubation for hypoxemia and work of breathing on HD2, and ECMO service was consulted on HD4 for refractory hypoxemia, once diagnosis was made of ARDS in association with pulmonary Blastomycosis. He remained well supported on venovenous ECMO for 59 days, but with recurrent pneumothorax and alveolar pleural fistulae, as well as dialysis-dependent renal failure. The severity of his lung injury was ultimately determined to be unrecoverable, and support was withdrawn.

Patient #2, a 57-year old male, presented as transfer from an outside hospital for consideration of ECMO support. He had presented 6 days prior with recurrent pneumonia, after failing outpatient therapy. His condition worsened and he required intubation the day prior to transfer for hypoxemia and ARDS. He was transferred and venovenous ECMO initiated on HD1. Diagnosis of pulmonary Blastomycosis was ultimately made after ECMO cannulation. The patient remained on extracorporeal support for 26 days, with a course complicated by multiple pneumothoraces and an episode of severe gastrointestinal hemorrhage. Following decannulation, he developed new and worsening systemic sepsis, gastrointestinal hemorrhage, and new hypoxemia. He expired on HD 37.

Given that ARDS in association with Blastomycosis infection has a very high mortality with conventional treatment, consideration should be given to the use of extracorporeal support in these patients, but many of the issues that arise with treatment of mechanical lung injury as well as chronic pulmonary disease also apply to these cases. Timeliness of therapy, management of physical lung injury, notably bullous cavitary lesions, and ethical considerations of prolonged support in single organ injury will all be discussed.
The Use of a CRRT Machine to Create Extracorporeal CO\(_2\) Removal in a Pediatric Patient

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**Introduction:** Extracorporeal CO\(_2\) removal (ECCO\(_2\)R) in patients with acute lung injury decreases further lung damage as a result of mechanical ventilation. In addition, ECCO\(_2\)R reduces the negative impact of elevated intrathoracic pressures on cardiac output and hemodynamics. We are presenting a case of a six-year-old female with end stage cystic fibrosis in whom we performed successful extracorporeal CO\(_2\) removal using a Maquet Quadrox-iD pediatric oxygenator in line with a continuous renal replacement therapy (CRRT) machine.

**Methods:** We initially performed an in-vitro trial using a Prisma Flex 0800 CRRT circuit and a Maquet Quadrox-iD pediatric oxygenator to establish education, procedure, and policy. In this simulation, we used simulated blood and different size catheters to assess flows and pressures across the CRRT membrane and oxygenator. We established that an 11 or 12 fr. catheter must be used to maintain a blood flow of 150 to 200 ml/min through the oxygenator. Patient selection according to policy includes patients with lung injury who require mechanical ventilation and renal replacement therapy. Policy requires that these patients also did not meet criteria for full ECMO support, dialysis catheters (11 or 12 fr.) could be placed, and had no contraindications for anti-coagulation.

One patient met the inclusion criteria. This patient was on very high ventilator settings with significant hemodynamic instability requiring inotropic support and was also in renal failure. An 11.5 fr. dialysis catheter was inserted percutaneously at the bedside into the right innominate vein. The CRRT return line was connected to the outflow of the Maquet Quadrox-iD pediatric oxygenator using a Medtronic ¼ perfusion adaptor. The outflow of the Maquet Quadrox-iD pediatric oxygenator was then connected to the dialysis catheter using another Medtronic ¼ perfusion adaptor. A heparin infusion was added to the inlet luer of the oxygenator in order to achieve therapeutic heparin assay levels. Once the CRRT was running, we added sweep gas to the oxygenator up to 6 liters per minute. We tested the amount of CO\(_2\) removal through the mechanical ventilator and the gas outlet port of the oxygenator. Using a GE ventilator with the respiratory metabolic cart, the total rate of elimination of CO\(_2\) including the rate of elimination of CO\(_2\) of the oxygenator were determined. We used a calculation that determined the elimination of CO\(_2\) which included the sweep flow and average exhaled CO\(_2\) using an end tidal CO\(_2\) monitor. The end tidal CO\(_2\) monitor was connected to the gas outflow of the oxygenator.

**Results:** Once the system was started, it was determined that the pediatric Quadrox-iD could extract up to 47 ml/min of CO\(_2\), which was about 40% of this patient’s total CO\(_2\) production. The patient was weaned from the ventilator and subsequently extubated on hour 87 of ECCO\(_2\)R. Inotropic support which included epinephrine and dopamine were decreased progressively at the start of ECCO\(_2\)R and weaned to off on hour 31. She remained extubated for the remainder of the therapy. The patient’s sedation was also reduced allowing her to have appropriate communication with her family. Once ECCO\(_2\)R was discontinued, the patient went back to intermittent hemodialysis for her renal support. ECCO\(_2\)R was well tolerated without complications lasting almost 6 days. The patient was eventually discharged from the ICU with improved respiratory status.

**Conclusion:** Extracorporeal CO\(_2\) removal in combination with CRRT in pediatric patients is feasible. Adequate blood flow is essential to maintaining proper oxygenator and CRRT function thus reducing the likelihood of complications. The same oxygenator was used throughout ECCO\(_2\)R support, and the CRRT circuit was changed out once because of institution protocol.

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An anti-Xa driven anticoagulation algorithm combined with routine replacement of antithrombin III is associated with reduced hemorrhagic and thrombotic complications as well as improved survival in post-operative pediatric patients supported with ECMO.

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**Abstract:** Background: In 2015 our ECMO program created institutional guidelines for the management of heparin anticoagulation for neonatal and pediatric patients supported with ECLS. These guidelines were highlighted by the following features: anti-Xa laboratory monitoring as the primary determinant of heparin titration; adjustments for clinical factors that influence heparin binding and elimination; adjustment of anticoagulation targets for patients deemed at risk for bleeding; and routine replacement of antithrombin III to keep ATIII activity greater than 60%. **Methods:** This retrospective analysis compared outcomes of children managed under the 2015 anticoagulation guidelines relative to outcomes of patients supported with ECMO in our institution from years 2013–2014. Thrombotic complications, defined as the need for an ECMO circuit change or limb ischemia requiring amputation, were assessed. Hemorrhagic complications were defined as bleeding requiring surgical intervention on ECMO and the development of intracranial hemorrhage. Other outcomes included blood product utilization, duration of ECMO, survival off ECMO, and survival to hospital discharge. Data was recorded as medians with interquartile ranges; comparisons were made via Wilcoxon Rank Sum p-values.

**Results:** 62 patients were included in the pre-guidelines group, and 81 patients in the post-guidelines cohort. Baseline characteristics were similar between the two groups, including gender, age, diagnoses, post-operative status, E-CPR utilization, ECMO modality, and ECMO cannulation strategy. There was a significant reduction in FFP utilization since initiation of the guidelines (95.8 vs. 30.5 ml/kg per ECMO run, p = 0.003). Likewise, there was a marked reduction in PRBC transfusions for cardiac ECMO patients (286 vs. 229.5 ml/kg per ECMO run, p = 0.05). Second, the number of ECMO runs requiring at least one circuit change decreased from 35.5% to 18.5% (p = 0.03). The rate of surgical interventions required for bleeding complications decreased from 29.5% of all ECMO runs down to 15.4% (p<0.05). There was a similar reduction in the incidence of intracranial hemorrhage (p<0.05). Lastly, there was a significant improvement in the survival of post-operative patients both off ECMO (69% vs. 90%, p<0.05) and to hospital discharge (44% vs. 72%, p<0.05). Within the post-guidelines cohort, patients who required an ECMO circuit change had a lower average daily ATIII activity relative to patients with no thrombotic complications (58.8% vs. 46.4%, p<0.05); interestingly, there was no difference in average daily ACT values nor average daily heparin doses between patients with and without thrombotic complications. Finally, ECMO days with an ATIII activity less than 50% and not repleted conferred an increased risk of requiring a circuit change within the subsequent 24 hours (OR 6.6, 95% CI 2.41–18.1, p = 0.002). ATIII supplementation was shown to be safe and cost-effective.

**Conclusion:** A pediatric ECMO anticoagulation guideline focused on anti-Xa driven heparin titration, adjustments for heparin binding and elimination, and routine replacement of ATIII is associated with a reduction in blood product utilization, thrombotic and hemorrhagic complications, and improved survival in post-operative patients. Furthermore, in our cohort, maintaining an average daily ATIII activity >50% appears to be protective against thrombotic complications without an associated risk of bleeding.

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ECMO strategy for severe ARDS complicated with septic shock
Yoshiaki Iwashita, Kei Suzuki, Masahiro Yukimitsu, Takashi Kato, Ken Sasaki, and Hiroshi Imai
Institution: Emergency and Critical Care Center, Mie University Hospital, POSTER presentation

[Introduction]
The use of extracorporeal membrane oxygenation (ECMO) for septic shock patients is controversial. We reviewed our experience with ECMO for severe ARDS patients complicated with septic shock to develop a treatment strategy for such patients.

[Methods]
We retrospectively reviewed severe acute respiratory distress syndrome (ARDS) patients with septic shock treated with ECMO in Mie University Hospital, Japan from January 2016 to July 2017.

[Results]
There were 5 cases during the period; three patients recovered from ECMO and were transferred for further rehabilitation, two died on ECMO.

All patients were treated initially on venovenous (VV) ECMO, and one was converted to veno-arteriovenous (VAV) ECMO. All cases showed increased mean blood pressure within 3h from VV ECMO start. In surviving cases, lactate was decreased in 2 of 3 patients within 3h from VV ECMO start, while it was increased in 2 of 2 in the fatal cases.

[Discussion]
Studies on ECMO for septic shock were mainly on VA mode. However, there are numerous limitations with VA ECMO because of its retrograde perfusion. From our experience, VV ECMO may improve the hemodynamic status as a result of decreasing the positive end-expiratory pressure (PEEP).

[Conclusion]
We propose our strategy of starting ECMO in VV mode and then conversion to VAV if lactate cannot be decreased within 3h from the start of ECMO.

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No Increase in Risk by Delaying Decannulation
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Objective
Risk factors for morbidity and mortality associated with extracorporeal membrane oxygenation (ECMO) support include intravascular cannulas and systemic anticoagulation. For this reason, cannula removal and stopping anticoagulation typically occurs soon after separation from ECMO. Our objective was to assess the risk in children of delaying decannulation following an ECMO run.

Methods
Between January 2014 and June 2016, 36 post-cardiotomy patients required ECMO. The patients included 20 neonates, 14 infants (median age 7 days and 2.5 months respectively), a 5 year old, and a 15 year old. Gender was equally divided. Overall survival to discharge was 47%. A retrospective analysis of ECMO runs was conducted. An ECMO run was defined as a period of time when a patient was placed on ECMO support and subsequently was either decannulated or died. In this cohort there were 42 ECMO runs; 31 patients had 1 run, 4 had 2 runs, and 1 had 3 runs.

Results
Of the 42 ECMO runs, 29 (69%) survived to decannulation. Of those ECMO runs that survived to decannulation, 18 (62%) were cannulated centrally and 11 (38%) were cannulated via the neck. For the runs where the patient survived to decannulation the mean number of days on ECMO support was 4 ± 2 days, and there was an average time interval of 21 ± 14 hours from ECMO termination to decannulation. During the interval of time from when the patient was separated from ECMO to decannulation, the cannulas were maintained by infusing 2 mL of normal saline per hour into which 1 unit of heparin had been added. A single patient failed being separated from ECMO support and 18 hours after separation required reinstitution of ECMO (but did not require re cannulation). Of the 42 ECMO runs, 29 (69%) survived to decannulation. Of those ECMO runs that survived to decannulation, 18 (62%) were cannulated centrally and 11 (38%) were cannulated via the neck. For the runs where the patient survived to decannulation the mean number of days on ECMO support was 4 ± 2 days, and there was an average time interval of 21 ± 14 hours from ECMO termination to decannulation. During the interval of time from when the patient was separated from ECMO to decannulation, the cannulas were maintained by infusing 2 mL of normal saline per hour into which 1 unit of heparin had been added. A single patient failed being separated from ECMO support and 18 hours after separation required reinstitution of ECMO (but did not require re cannulation). Of the 29 survivor runs, PRBC’s were transfused after separation from ECMO but prior to cannulation in 9 (31%) cannulated centrally and 3 (10%) cannulated via the neck. No wound infections were observed prior to hospital discharge or death. Stroke occurred during the ECMO run in 3 (10%), but did not worsen prior to decannulation. For the 26 runs without stroke, no new evidence of stroke was observed prior to decannulation.

Conclusions
We conclude that delaying cannula removal after separation from ECMO is safe. It does not appear to increase the risk of wound infection or stroke. Cannulation in the neck lessoned the need for blood transfusion prior to decannulation. The difficulties involved in cannulation after a run of ECMO may cause providers to hesitate before separating from ECMO or not offer a second ECMO run to an eligible patient. We have found that separating from ECMO, but leaving the cannulas in place, lowers the threshold for trialing off ECMO and provides an easy transition back onto ECMO should another run be required. Leaving the cannulas in place does not appear to increase risk.

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ECMO Support for Pediatric Burn Patients: Is it Worth the Risk?
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Objective: Extracorporeal membrane oxygenation (ECMO) has been used as life-saving support for children with varying causes of respiratory and/or cardiac failure. However, few studies have assessed the utility of ECMO as a viable treatment option in the setting of pediatric burn injury. We aim to examine the outcomes of pediatric burn patients requiring ECMO support by utilizing the Extracorporeal Life Support Organization (ELSO) registry in order to elucidate whether or not ECMO should be considered in this population.

Design/methods: A retrospective cohort study was conducted by querying the ELSO database for all pediatric patients (birth to less than 18 years) who were supported on ECMO with burn-associated cardiopulmonary failure between 1990 and 2016. ICD-9 codes 940–949.5 were utilized to identify patients with an associated burn injury. Venovenous ECMO was defined as any patient with only venous cannulas, including double-lumen venous cannulas. Venoarterial ECMO was defined as any patient with a venous and an arterial cannula, any patient originally supported on VA ECMO that was converted to venovenous, or any patient originally supported on venovenous that was converted to venoarterial ECMO. Oxygenation indices (OI) and complication rates were compared among survivors and non-survivors for both venovenous (VV) and venoarterial (VA) groups. Non-parametric descriptive statistics were conducted and statistical significance was set a priori at p <0.05.

Results: A total of 113 patients met inclusion criteria for the study. Overall survival to discharge was 52.2% (n=59) for the entire cohort. Seventy-three patients were supported on VA ECMO, while 37 patients required VV ECMO support with a survival to discharge of 47.9% (n=35) and 62.2% (n=23), respectively. There was no statistical difference for median age (p=0.765), median weight (p=0.932), or median hours on ECMO (p=0.963) between survivors and non-survivors. Three patients did not have the type of cannulation identified but were listed as “other” in the ELSO registry.

Patients requiring ECMO support for respiratory failure had a higher overall survival (55.7%, n=97) compared to those requiring ECMO for cardiac failure (33.3%, n=6) or ECPR (30%, n=10). Patients who were supported on VV ECMO for respiratory failure had the best overall survival at 62.2% (n=37) and those cannulated to VA ECMO for respiratory failure had a survival of 51.7% (n=58). Patients supported on VA ECMO for cardiac failure or ECPR support had the same survival at 33.3% (n=6 and 9 respectively).

One hundred patients suffered mechanical or patient-related complications. There were 293 complications in the VA group (n=68, 55 mechanical, 238 patient) vs. 144 in the VV group (n=30, 33 mechanical, 111 patient). Overall complication rates between venoarterial and venovenous groups were not statistically significant (p=0.101). Rates of surgical site bleeding for VV ECMO and VA ECMO were similar 18.9% (n=7) and 21.9% (n=16) respectively.

Conclusion: Overall survival for pediatric burn patients requiring ECMO support is comparable to other pediatric ECMO patients with those requiring ECMO for respiratory support having the highest survivability. As such, ECMO should be considered as an additional level of support for the pediatric burn population, especially in the setting of respiratory failure. Additional studies are necessary to determine the optimal timing of ECMO support and patient characteristics that may impact outcomes.

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The views expressed in this article are those of the †FM_Authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense or the U.S. Government.
Neonatal-Pediatric Extracorporeal Membrane Oxygenation (ECMO) in a Developing Latin American Country: 15 Year Experience in a Chilean ECMO Center

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Background: In 1972 and 1975 ECMO was first used successfully with neonatal-pediatric patients with cardiac and respiratory failure, respectively, that were unresponsive to maximum therapy. ECMO is actually used in the neonatal-pediatric field as a rescue therapy, with more than 1,300 patients with respiratory failure and close to 1,200 patients with cardiac diseases reported each year. The first neonatal-pediatric ECMO Program in Chile was established at the “Hospital Clínico Universidad Católica de Chile” (ECMO-UC center) in 2003, and it was also the first Latin American Program affiliated to the Extracorporeal Life Support Organization (ELSO).

Objective: To review ECMO survival, complications and follow-up of neonatal and pediatric patients in developing Latin American countries in 15 years.

Design/Methods: Data of all patients with cardiopulmonary failure who required ECMO, between May 2003 and July 2017, were analyzed.

Results: From May 2003 to July 2017, the ECMO-UC center treated 195 patients (167 newborns and 28 children, ranged from 0 to 11 years of age), with both severe respiratory and cardiac diseases. 71% of these newborns and children survived to hospital discharge and are currently in follow-up. The highest survival rate to discharge was seen in newborns with meconium aspiration syndrome (MAS) 92%, and pneumonia 88%. The largest number of patients treated was the congenital diaphragmatic hernia (CDH) group, with a 68% survival rate to hospital discharge (69/101). Survival to discharge in cardiac ECMO cases was higher in newborns (76% vs 52% in children), especially in patients with total anomalous pulmonary venous return (80%). The primary diagnoses in 57 patients that died were: CDH (n = 32), congenital heart diseases operated with failure to wean from cardiopulmonary bypass or arrhythmias (n = 13), persistent pulmonary hypertension (PPHN) secondary to sepsis, pneumonia, MAS, SP-B or ABCA3 deficiency or without defined cause (n = 11), and pneumonia due to Bordetella pertussis (n = 1). The neurological follow-up results were: Bayley II scale at 12–18 months showed that 92% of the children had normal or slightly altered mental development index (MDI) and 70% had normal or slightly altered psychomotor development index (PDI). In CDH patient’s follow-up, 82% had a normal MDI, and similar to the entire group, over 72% had a normal or slightly altered PDI.

With respect to respiratory follow-up at 3 years, 83% of them were clinically normal or with a slight altered evaluation, and 27% had moderate bronchial hyperreactivity.

Conclusions: After 15 years, the first neonatal-pediatric ECMO program has been consolidated in Chile. The survival rate to discharge was high compared to ELSO reports. Among our patients treated with ECMO, CDH was the single most frequent diagnosis. ECMO therapy was successful, and was not associated with disabling neurological sequelae in most patients.

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Cardiac Output Increases with Transfusion of Stored RBCs is partially offset with RBC Rejuvenation – A Simulation Study

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Background: Red Blood Cell (RBC) metabolic changes during liquid storage increase the affinity of hemoglobin (Hb) for oxygen (O2) that leads to impaired oxygen delivery (low p50) to tissues when compared to fresh circulating RBCs (Hasan 1994). An FDA-approved extracorporeal rejuvenation solution (Citra Labs) restores ATP and 2,3-DPG in RBCs to normal levels, normalizing membrane function and oxygen affinity, respectively. Rejuvenated RBCs have demonstrated improved cardiac index, oxygen availability, and a greater arteriovenous content difference in cardiac surgery (Dennis 1978). The Cardiac Output (CO) required to maintain normal oxygen consumption (VO2) was estimated after a series of simulated transfusions of either standard or rejuvenated RBCs stored up to 42 days in an in vitro model.

Methods: VO2 was calculated using oxygen dissociation curves (ODC) generated from standard leukocyte reduced RBC units (n = 52) at Day 0 (Fresh), after storage for 42 days, and after rejuvenation and washing on day 42 (rejRBC) with a rejuvenation solution using the method previously reported (Srinivasan 2017). Five additional standard RBC units were evaluated after 7 and 21 days of storage to provide ODCs at intermediate time points. The average oxygen release capacity at Day 0 and a normal 5 L/min CO were used to establish a pre-surgery baseline VO2, of 229 ml O2/min. The simulated transfusion model determined CO requirements to maintain baseline VO2 by utilizing oxygen release capacity after a transfusion trigger of 9 g/dL and transfusion of 5 RBC units to maintain a patient hemoglobin of 10 g Hb/dL, assuming a 1 g/dL loss between transfusions (i.e. bleeding, pump induced hemolysis, blood draws). A constant blood volume of 5 L and baseline Hb of 14 g/dL was assumed. Physiological conditions to counteract hypoxia, other than an increase in CO were not considered in this model.

Results: The CO required to maintain baseline VO2 increased 56% from 5 L/min to 7.8 L/min at a Hb of 9 g/dL, assuming all other physiological parameters were held constant. CO increased with each transfusion of standard stored RBCs. Fresh RBCs maintained a constant CO and rejRBCs reduced the required CO after each transfusion.

Conclusion: In this simulated transfusion model, CO increased to maintain the pre-surgery baseline oxygen consumption. CO increased with RBC storage duration except when the RBCs were rejuvenated to restore the oxygen release function. Optimally fresh (Day 0) RBCs, although not available clinically due to screening requirements, required a 40% increase in CO to maintain pre-surgery baseline oxygen delivery primarily due to decrease in Hb concentrations while rejuvenation of 42 day old RBCs only increased CO by 16% at the same Hb concentration. Traditionally, transfusion of RBCs less than 7 or 14 days have been considered fresh and often are used in high-risk patient populations. Transfusion strategies targeting physiological normal oxygen consumption, rather than prespecified hemoglobin transfusion triggers may offer an advance in patient care. Clinical research is planned, to validate improved oxygen transport through RBC rejuvenation.

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Histopathologic Findings in Adult Recipients of Extracorporeal Membrane Oxygenation

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Introduction: Neurologic injury is not uncommon in adult recipients of venoarterial (VA) and venovenous (VV) extracorporeal membrane oxygenation (ECMO). Although clinical and radiologic injury is well-described in literature, the types of histopathology are not. In this case series, we describe abnormal findings of brain autopsies in adult ECMO recipients.

Methods: A retrospective chart review was conducted of adult decedents who received VA or VV ECMO from January 2003 to May 2015 at the University of Maryland Medical Center and underwent brain autopsy. Baseline demographic data, ECMO type, reason for cannulation, location of cannulation, and neuroimaging results were all collected. Last known neurologic exam prior to death was documented in the form of Glasgow Coma Score (GCS), and reason for death was documented. Brain autopsy specimens were reviewed with neuropathologists and results categorized by dominant patterns of injury.

Results: Twelve decedents underwent brain autopsy during the study period. One patient’s specimen was unable to be retrieved, and 11 patients were reviewed. Seven (64%) had abnormal brain pathology, while 4 (36%) had no abnormalities. Patients with abnormalities were younger (45 vs. 52 years old), on ECMO for shorter duration (18 vs. 36.5 days), had a lower median last known GCS (6 vs. 8), and received more CT scans (4 vs. 1). In the abnormal pathology group, 4 (57%) patients received VV ECMO (all for ARDS) and 3 (43%) received VA ECMO: 1 (14%) for cardiac arrest/ECPR, and 2 (29%) for cardiogenic shock. In this group, 5 patients (71%) had microhemorrhages on autopsy, while hemorrhage was noted on 1 CT scan. Five patients had signs of hypoxic brain injury, and 1 patient showed signs of edema. One patient had microinfarctions, and two had necrosis and infarction of the anterior pituitary. One of these patients was pregnant, while the other was a male.

Conclusion: Brain injury in recipients of ECMO is varied and may not be seen on neuroimaging. Further studies should be undertaken to explore associations between clinical factors, abnormalities on neuroimaging, and patterns of histologic damage.

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Elevated initial regional brain oxygenation values may predict poor outcome in patients placed on veno-arterial ECMO

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Introduction: Cerebral injury is increasingly described in adult recipients of extracorporeal membrane oxygenation (ECMO) therapy. We describe the association between regional brain tissue oxygenation (rSO2) measured by near infrared spectroscopy (NIRS), survival, and cerebral injury on neuroimaging.

Methods: A single-center retrospective chart review was conducted of adult patients who underwent veno-arterial (VA) ECMO from April 2016 to October 2016. All patients had received NIRS monitoring during ECMO therapy. Baseline demographics, in-hospital complications, and mortality were recorded. Desaturations of rSO2, defined as decline >25% below baseline or absolute value <40, were recorded and analyzed. Desaturation burden was calculated by area under the curve analysis and measured by rSO2*seconds.

Results: Eighteen VA ECMO patients underwent NIRS monitoring during the study period. 11/18 patients experienced desaturations. These patients had non-significant trends in age (50.2 vs. 64.7), sex (8 females vs. 1), ejection fraction (28.6% vs. 46.4%) and liver dysfunction (7 patients vs. 1). Patients with desaturations were more likely to have abnormalities on CT scan (6 vs. 0, p = 0.04). Eleven of the 18 patients survived to discharge. Survivors had no significant difference in baseline demographics, but had lower initial ECMO sweep (4.1 vs. 6.7, p = 0.008). Survivors had lower baseline rSO2 values at the beginning of NIRS monitoring (right – 57 vs. 65, p = 0.04, left – 57 vs. 68, p = 0.05), and non-significant trends in desaturation events (7 vs. 14), lower desaturation burden, and total desaturation duration (1:21 vs. 3:09 hours).

Conclusions: Baseline rSO2 values may predict outcome in patients placed on VA ECMO. Further studies in larger patient populations are warranted to investigate correlations between desaturation on NIRS and cerebral injury and prognosis.

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Reposition of a dual lumen VV–ECMO cannula using a retrograde venous wire without disruption of extracorporeal support.

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Introduction

ECMO support via dual lumen single cannula support is now commonplace. Although rare, cannulas inserted through the IJ can become displaced with minimal manipulation. To correct a displaced catheter typically requires that ECMO support is discontinued to allow wire insertion through the cannula to redirect the cannula into proper position. However, some patients cannot tolerate disruption of extracorporeal support. We describe such a case and a method to reposition an dual lumen cannula without disruption of extracorporeal support.

Case Report

An 8 month/old presented with severe bilateral viral pneumonia requiring VV-ECMO support with a single cannula dual lumen catheter (16F). After 24 hours of support there was a significant drop in Qb and decreasing O2 saturation. A CXR reveal that the cannula had migrated into the RV as shown in Figure 1. Because the patient was fully dependent on ECMO support, disruption of ECMO was not possible. There were multiple attempts to redirect the catheter under US and X-ray guidance without success.

Procedure

The femoral vein was cannulated with a 4.0 F micro-puncture kit. A 0.35 wire was then inserted through the introducer and advanced into the dual lumen cannula at the RA/SVC junction (see Figure 2). A second operator advanced the cannula over the wire into the IVC and into acceptable position (see Figure 3). There was no disruption on ECMO Qb or significant desaturation. The Figure 3 introducer remained in place but the wire removed.

Conclusion

Although this technique will seldom be required, it is a method to reposition a dual lumen venous cannula without disruption of VV-ECMO support.

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Veno-Arterial Extracorporeal Membrane Oxygenation as Hemodynamic Support During Ventricular Tachycardia Ablation


Introduction: In patients with structural heart disease, ventricular tachycardia (VT) is a significant cause of morbidity and mortality, as it is often associated with significant hemodynamic compromise, particularly in patients with an advanced cardiomyopathy. While an effective treatment for VT, catheter ablation often involves induction of the VT and results in profound hemodynamic instability. Circulatory support during VT ablation has been described with intra-aortic balloon counterpulsation, percutaneous left ventricular assist device, and, in a few instances, veno-arterial extra-corporeal membrane oxygenation (VA-ECMO). We report outcomes of patients who underwent VT ablation with VA-ECMO support at our institution.

Methods: We retrospectively reviewed charts of patients in our center supported with VA-ECMO for incessant VT between 03/2013 and 7/2017 and identified those who underwent VT ablation while on VA-ECMO. Data collected included baseline characteristics, echocardiographic data, details of the ablation procedure, and clinical outcomes.

Results: Of 16 patients supported with VA-ECMO for incessant VT, 5 underwent catheter ablation during support. All patients underwent VT ablation while on VA-ECMO; one patient also had a percutaneous left ventricular assist device and another had an intra-aortic balloon pump. In four patients, thorough activation and entrainment mapping was made possible due to unperturbed hemodynamics with VA-ECMO support. Four patients (80%) underwent successful catheter ablation of VT; of these, 1 required a single shock for recurrent VT during the hospitalization. Four ablations utilized activation mapping, while one utilized substrate modification. One ablation was unsuccessful due to the presence of both a left ventricular thrombus and extensive epicardial adhesions limiting access. Three (60%) patients survived to hospital discharge. One expired from complications of pneumonia without further VT post ablation and the patient unsuccessfully ablated had VA-ECMO support withdrawn due to hemolysis and developed worsening VT. Baseline and outcomes data are presented in Table 1.

Conclusions: In high risk patients, VA-ECMO circulatory support can be used as an assist device to achieve effective catheter ablation, though overall outcomes depend on patient co-morbidities.

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Table 1. Outcomes of VT Ablations performed with VA-ECMO Support

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Cardiomyopathy</th>
<th>Etiology</th>
<th>LVEF (%)</th>
<th>LVEDd (cm)</th>
<th>Clinical VT Successfully Ablated</th>
<th>Mapping Strategy</th>
<th>Additional Device to VA-ECMO</th>
<th>Days on VA-ECMO</th>
<th>30-Day Survival</th>
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<td>IABP</td>
<td>8</td>
<td>No</td>
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LVEF, left ventricular ejection fraction; LVEDd, left ventricular end diastolic dimension; VT, ventricular tachycardia; AM, activation mapping; SM, substrate modification; VA-ECMO, veno-arterial extra-corporeal membrane oxygenation
Hospital-Acquired Pressure Injury (HAPI) Prevention in Adult ECMO Patients
Erin A Lomas BSN RN CCRN-CSC-CMC | Jason Felt BSN RN CCRN | Matt Hammond RN CCRN | Chris Meyers MSN RN | Amanda Browne ARNP | John Mignone MD PhD

Background: Hospital-Acquired Pressure Injuries (HAPI) are a costly complication affecting approximately 10–40% of all Intensive Care Unit (ICU) patients. HAPIs are costly for hospitals, both in treatment and in length of stay, and add additional complications to already complex patients. In 2015, the Cardiovascular Intensive Care Unit (CVCU) at Swedish Medical Center in Seattle, WA cared for nine adult ECMO patients, five of whom developed a total of 11 HAPI. Our ECMO Specialist RN Staff and Mechanical Circulatory Support Committee prioritized the reduction of HAPI in our ECMO patients for the following year.

Approach: In 2016, we developed a comprehensive HAPI prevention bundle for our ECMO patients, which was presented to our ECMO Specialist RNs and implemented in each of our 12 ECMO patients. This bundle has not only been added to our ECMO Standards, but also to our ECMO order set. Additionally, our ECMO Specialist RNs document all HAPI prevention measures in a template ECMO Shift Summary Note. Our bundle includes:

- Silicone dressing placement to all posterior bony prominences (i.e. sacrum/coccyx, spine, scapulae) prior to cannulation or shortly after
- Maintaining no more than three layers between the patient and low-air loss mattress
  - Fitted Sheet (bottom layer)
  - Blue TAPS Sheet (middle layer)
  - One layer of disposable air-flow pads to keep TAPS sheet clean (top layer)
- Tilting the patient every 2 hours with TAPS wedges
- Utilizing pediatric gel pillow beneath bony prominences to relieve pressure (i.e. elbows, shoulders, occiput, wrists)
- Repositioning of patient’s head every 2 hours
- Repositioning circuit tubing every 2 hours and placing a gel pillow or ABD pad beneath tubing to more evening distribute pressure to skin (if impossible to completely keep tubing off patient’s skin)
- Placement of soft boots on patient’s feet immediately post-cannulation (these elevate heels)
- Removal of Sequential Compression Devices (SCDs) every shift to assess skin
- Repositioning endotracheal tube every 2 hours (alternating left side, right side, and midline)
- Replacing endotracheal tube securement device every 5–7 days or if it no longer fits well
- Considering placement of fecal management device if patient having frequent liquid stools
- Use of zinc moisture barrier cream to buttocks and skin folds
- Initiating enteral trickle feeding 12 hours post-cannulation

Results: After implementing our HAPI prevention bundle, our incidence of HAPI in ECMO patients went from 11 to zero! In 2015, we cared for 9 ECMO (VV and VA) patients with an average run length of 8.2 days (74 total ECMO days; longest run 28 days, shortest run less than 1 day). In 2016, we cared for 12 ECMO patients with an average run length of 7.8 days (94 total ECMO days; longest run 21 days, shortest run 2 days).

Discussion: In 2016, our patients experienced shorter runs overall, with 58% having a run time of 4 days or less; in 2015, only 44% of patients had a run time of 4 days or less. Additionally, we were slower to initiate and advance tube feedings in 2015. Prior to 2016, our nursing staff was without the means to effectively and safely reposition ECMO patients, leaving many with severely limited repositioning. Furthermore, support and compliance from our ECMO Specialist RNs was critical to the significant reduction of HAPI in our ECMO patients.

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Novel Leg Cannula for Venous Decompression in Peripheral Extracorporeal Membrane Oxygenation for Septic Adolescents
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Willing to Both poster and oral presentation.
A chimney femoral artery graft for peripheral extracorporeal membrane oxygenation can potentially cause hyper-perfusion and subsequent venous congestion in the ipsilateral leg, especially in the context of septice shock and higher flow requirement. A leg venous cannula can directly and effectively decompress leg congestion caused by hyper-perfusion, decrease the arterial resistance, and restore distal leg perfusion. Furthermore, the venous leg cannula can help to achieve overall higher flow by providing extra venous return. Here we report two septic adolescents who were supported by peripheral veno-arterial ECMO, who were successfully rescued by adding a leg venous cannula for venous decompression. This novel femoral (V) femoral (V)-femoral (A) configure could be potentially used in ECMO for septic shock as an alternative of central cannulation.

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Acute Kidney Injury, Fluid Overload, and Outcomes in Neonatal and Pediatric Patients Supported with Extracorporeal Membrane Oxygenation for Respiratory Failure
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Introduction: Children who receive ECMO commonly develop acute kidney injury (AKI) and fluid overload (FO). The purpose of this study is to evaluate the association between AKI, FO and mortality in children supported with ECMO for refractory respiratory failure.

Methods: This is a retrospective observational cohort study of pediatric patients on ECMO at six centers from January 1, 2007 until December 31, 2011, performed by the Kidney Interventions During Extracorporeal Membrane Oxygenation (KIDMO) study group. Data sources include the Extracorporeal Life Support Organization (ELSO) registry and the individual study sites. Demographic data and pre-ECMO variables pertaining to severity of illness were collected. ECMO variables included ECMO indication, support mode, ECMO duration, and non-renal complications. Percent FO (cumulative fluid balance/ICU admission weight X 100) was calculated before, during, and after ECMO. AKI was defined by serum creatinine and the need for renal support therapy (RST) criteria per the Kidney Disease: Improving Global Outcomes (KDIGO) criteria.

Results: This analysis includes 424 patients supported with ECMO for respiratory failure. The median age was 3 days (IQR 1 – 218.5 days). The study group includes 271 neonatal patients (< 30 days) and 153 pediatric patients (≥ 30 days). Two hundred and seventy four patients (64.9%) had AKI. Twenty percent of patients with AKI died on ECMO, while 9.5% of patients without AKI died on ECMO (p=0.003). One hundred eighty seven patients (44.3%) received RST. The need for RST was associated with ECMO mortality; the ECMO mortality rate of those requiring RST was 20.8%, compared with 9.5% for those who did not require RST (p=0.004). At the time of cannulation, the median oxygenation index was 48.1 (IQR 36.6 – 71.1), and the median serum pH was 7.2 (IQR 7.1 – 7.3). Three hundred seventy one patients (87.5%) received inotropic support. Forty-two percent of patients had >10% FO at time of ECMO initiation. FO level at time of ECMO initiation was not associated with hospital mortality. Hospital survivors had an initial FO level of 7.8% and non-survivors had an initial FO level of 7.7% (p=0.70). Ninety percent of patients had a FO of >10% during ECMO, and 33.7% had a peak FO of >50%. Peak FO’s during ECMO was significantly associated with hospital mortality. The median peak FO% in patients who did not vs. did survive to hospital discharge was 52% (IQR 31.5 – 85.3) vs. 27.2% (IQR 15.9 – 49.9), respectively (p= 0.0001). Patients who died experienced peak FO on ECMO day 9 (IQR 2 – 17.5), whereas those who survived experienced peak FO earlier on ECMO day 3 (IQR 2 – 9) (p= 0.0001), suggesting that progressive FO while on ECMO is associated with mortality. Additionally, patients who did not survive to hospital discharge had a median FO% of 51.4 (IQR 27.8 – 82.6) at time of ECMO discontinuation, vs. 23.2% (IQR 11.4 – 44) for survivors to hospital discharge (p= 0.0001).

Conclusion: In neonatal and pediatric patients supported with ECMO for refractory respiratory failure, AKI and FO are associated with increased mortality. Our results demonstrate the significant burden that AKI and FO have on ECMO patients. Further study is needed to discern whether interventions to prevent and reduce AKI and FO can lead to improved outcomes.

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Submission for poster presentation, oral presentation, or both.
Cardiac arrest caused by massive pulmonary embolism, survival using extracorporeal membrane oxygenator; a single center retrospective study.

L. Mandigers, MD, D. Gommers, MD, PhD, D. dos Reis Miranda, MD, PhD

Abstract:
INTRODUCTION/BACKGROUND: Mortality rates in cardiac arrest patients due to massive pulmonary embolism (PE) are very high, most probably because of the difficulty of cardiopulmonary resuscitation (CPR) caused by the right ventricular outflow obstruction. In patients with massive PE who do not need resuscitation, veno-arterial extracorporeal membrane oxygenation (vaECMO) has a superior survival compared to patients who are not treated with vaECMO.(1) We hypothesized that patients suffering from cardiac arrest as result of a pulmonary embolism will also benefit from vaECMO during CPR.

PATIENTS AND METHODS: We retrospectively identified 18 patients, in the period of January 2012 till March 2017, with massive PE, which received Extracorporeal Membrane Oxygenation (ECMO) during cardiac arrest. The main study endpoint is the Cerebral Performance Category (CPC) score by using a questionnaire. In the conventional resuscitation arm, we retrospectively identified 21 patients suffering from cardiac arrest, caused by PE (who were given thrombolysis due to dilated right ventricle during CPR) in a period from January 2012 till July 2014. In our institution, ECPR for PE was added to the protocol in 2015.

RESULTS: From 2012, 6 of the 18 patients treated with ECMO after cardiac arrest due to massive PE survived (33%). 5 of them returned a complete questionnaire. 4/5 participants had a CPC ≤ 2 at point prevalence and 1 patient had a CPC score of 3. Of all conventional treated patients after cardiac arrest due to massive PE, 1/21 had a CPC ≤ 2.

CONCLUSION: Considering the high mortality rates after massive PE, vaECMO during cardiac arrest is promising in increasing survival rate with good neurological outcome.

Reference:

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Volume overload, acute kidney injury, and fluid balance management in patients transferred to a large volume ECMO center
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University of Maryland Medical Center, Baltimore, Maryland

Introduction: Extracorporeal membrane oxygenation (ECMO) is being used with increasing frequency for a variety of cardiac and respiratory indications. Early referral to higher volume ECMO centers is associated with improved outcomes. Volume overload and acute kidney injury are common in ECMO patients and are associated with worse outcomes. The purpose of this ongoing study is to determine if volume overload, acute kidney injury, fluid balance and fluid balance management have a relationship with outcomes in patients transferred to an ECMO center

Methods: We report data of a single center registry of patients transferred for and placed on VA or VV ECMO January 2016 and May 2017.

Results: A total of 128 patients were in this registry with a median age of 52 years and 59% of the patients were male. Sixty-five percent of the patients were managed with VV ECMO with the most common indications being ARDS, pneumonia, and obstructive lung disease/hypercapnic respiratory failure. Thirty-five percent of the patients were managed with VA ECMO with the most common indications being cardiogenic shock and pulmonary embolism.

Over 80% of patients were reported as fluid overloaded on initial history and physical and over 60% of patients had acute kidney injury on presentation. The survival these patients is over 70%. A positive fluid balance was common over the first two hospital days but was much less common by hospital day five. Over half the patients received a diuretic while on ECMO and about 70% of patients received at least one day of ultrafiltration and/or continuous renal replacement therapy while on ECMO. About 20% of patients received at least one session of hemodialysis during their hospital stay.

In this early analysis, there appears to be an association between initial volume overload, acute kidney, and fluid balance with poor outcome. Further analysis is ongoing.

Conclusions: Volume overload and acute kidney injury are common among patients transferred from outside hospitals for ECMO. In this series, a positive fluid balance was common over the first two hospital days and much less common by hospital day five. Both diuretics and ultrafiltration/continuous renal replacement therapy were used in most patients to manage fluid balance while on ECMO. Although the survival was high in this series, there appears to be an association with volume overload, acute kidney injury and positive fluid balance with mortality.

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Exploring the Use of Extracorporeal Membrane Oxygenation (ECMO) as a Bridge to Organ Donation in a Pediatric Cardiac Patient: a Unique Case Report
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Background: In April 2017, a 13-year-old male was admitted to a regional children’s hospital for a same day cardiac catheterization. The patient presented with a significant history of morbid obesity, surgical arterial switch with an aortic arch repair related to transposition of the great arteries, and multiple previous balloon stent angioplasties for pulmonary stenosis and aortic arch obstruction. A diagnostic catheterization was planned involving balloon dilation of existing stents and possible placement of new pulmonary artery stents. Following dilation of existing stents and placement of a new left pulmonary artery stent the patient experienced a drop in oxygen saturations from 95% to 90% requiring increased ventilator support. During fluoroscopy, haziness of the left lung was noted which was not present before the start of catheterization and the procedure was aborted due to strong suspicion of a left lung reperfusion injury. Although the patient had received one IV dose of methylprednisone (125mg) and Lasix (20mg) to prevent such injury, the decision was made to maintain the patient on ventilator support overnight and transfer to the pediatric intensive care unit (PICU) for further medical management. Immediately upon arrival to the PICU, the patient acutely decompensated- oxygen saturation 88% on 100% FiO2, heart rate 113, and arterial blood pressure 88/53. Within 78 minutes the cardiothoracic surgeon was called to the patient’s bedside to evaluate the patient for ECMO. A collaborative decision was made to volume resuscitate the patient and optimize ventilator support. The patient showed temporary improvement in oxygen saturations and arterial blood gases, but within an hour of intervention the patient decompensated again and the decision was made to proceed with ECMO cannulation.

ECMO Course: The patient proved to be a complex cannulation due to femoral vessel damage from multiple cardiac caths and extensive scar tissue from a previous sternotomy. Ultimately, the patient was cannulated with a 21 fr arterial cannula in the carotid artery and a 23 fr venous cannula in the internal jugular vein. Since the patient was receiving adequate oxygenation and perfusion on 2.5L/min of flow, the decision was made to maintain current flows and remain on low dose vasopressors, instead of attempting to increase flow support to the weight-based target of 14L/min. A plan was in place for the patient to undergo an atrial septostomy the following day in hopes of off-loading the left heart and improving native cardiac function. However over the next 12 hours the patient developed pupillary changes significant for central nervous system deterioration. The patient was transported to radiology for a CT scan which revealed diffuse cerebral parenchymal edema with mass effect, including effacement of ventricles and basal cisterns and suspicion of impending uncal herniation. Neurosurgery was consulted but no surgical intervention was deemed appropriate and the extremely grave prognosis was presented to the family. The patient’s family was adamant about not prolonging the patient’s life considering this recent change and expressed a strong desire for organ donation. Skepticism arose regarding viability of organs in light of current ECMO support, therefore the regional transplant foundation was contacted for evaluation and donation after cardiac death was explored. However over the next 12 hours the patient progressed to brain death and traditional pathways of organ donation were initiated.

Conclusions/Implications: A comprehensive medical evaluation was completed and organs were procured on day 3 of ECMO. This patient became the first in the region, of all age groups, to donate an organ while on ECMO support. The patient’s organs were successfully transplanted and to this date the recipients show no signs of organ rejection per reports. In our opinion, ECMO as a bridge to organ donation is under-explored and under-utilized. This strategy of utilizing ECMO offers the potential for increasing the number of patients who meet donation criteria and are able to donate viable organs.

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Outcomes of ECMO Support as a Bridge TO or FROM Cardiac Transplantation
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Abstract: Acute cardiac failure supported with extracorporeal membrane oxygenation (ECMO) is now more common in modern medical care and may be required either before or after cardiac transplantation. This study examines short and mid-term outcomes of patients who required ECMO before or after cardiac transplantation.

Methods: A retrospective chart review of all patients who required ECMO at a single institution from 2006 to January 2017 was conducted. Patient characteristics, hospital course, and outcomes were collected. Cohorts were defined in terms of which event came first, ECMO support or transplant: the pre-transplant group included all patients requiring ECMO any time before cardiac transplantation, and the post-transplant group included all patients who required ECMO at any point after cardiac transplantation. Descriptive statistics were used to summarize the data. Continuous and categorical data were compared between cohorts.

Results: 55 patients were identified who required both ECMO and cardiac transplantation. 25 patients required ECMO at some point prior to transplant, and 30 patients underwent transplantation and subsequently needed ECMO. Overall, 76% of patients were weaned from ECMO support, and 67% were discharged alive. 60% of patients remained alive at last follow up. Median follow up was 715 days and did not differ significantly between groups. There were no statistically significant differences in median age, duration of support, baseline creatinine, total red blood cell (RBC) transfusions, RBC units per day on ECMO and length of stay for transplant admission.

In the pre-transplant group, ECMO may have been remote, preceding cardiac transplant by a median of 148 days. Post-transplant tended to need ECMO immediately after transplant with median separation of the two events of 1 day (p <0.0001). The pre-transplant patients more commonly had an assist-device, though this did not reach statistical significance. Thirty-day transplant survival was better for patients who required ECMO before transplant rather than after (96% versus 43%, p <0.0001). At last known follow up, more patients in the pre-transplant group were still alive (96% versus 30%, p < 0.0001).

Conclusions: Compared to published overall ECMO outcomes, the short-term survival for patients who require both ECMO and cardiac transplant are excellent. Likewise, results were superior to published overall two-year survival rates of all cardiac transplant patients for patients who required ECMO prior to transplant. This study reinforces ECMO as a salvage strategy for cardiogenic shock, offering potential for good long-term results through transplantation, even in the absence of a full cardiac recovery. These results support ECMO as a practical method to bridge well-selected patients both to and from cardiac transplantation.
In Vitro Evaluation of ECG-Synchronized Pulsatile Flow Using i-Cor Diagonal Pump in Neonatal and Pediatric ECLS Systems

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Objective: The purpose of this study was to assess the novel i-cor electrocardiogram (ECG)-synchronized cardiac assist system in terms of hemodynamic energy properties for neonatal and pediatric ECLS circuits. Total hemodynamic energy (THE) is a measure of the energy carried by blood, where higher levels of THE delivered to the patient are associated with increased microcirculation and organ perfusion. While the Food and Drug Administration (FDA) has not yet approved the i-cor diagonal pump for use in the United States, the pump is used in Europe and holds significant clinical and research implications.

Methods: The neonatal circuit consisted of an i-cor diagonal pump and console, a Medos hilo 800 LT oxygenator, an 8Fr arterial cannula, a 10Fr venous cannula, 3 feet of 1/4-inch ID arterial tubing, and 3 feet of 1/4-inch ID venous tubing. The pediatric circuit was identical to the neonatal system except it included a 12Fr arterial cannula, a 14Fr venous cannula, and a Medos hilo 2400 LT oxygenator. The circuit was primed with lactated Ringer’s solution and packed red blood cells (hematocrit 40%). Neonatal trials were conducted at 36°C using varying flow rates (200–600 mL/min with 200 mL increments) and post-arterial cannula pressures (40 and 60 mmHg) under non-pulsatile mode and pulsatile mode with various pulsatile amplitudes (1,000–4,000 rpm with 1,000 rpm increments). Pediatric trials were conducted under similar conditions but different flow rates (800–1,600 mL/min with 400 mL increments). Pressure and flow waveforms were recorded for all trials using a custom-made data acquisition system.

Results: Mean pressure and energy equivalent pressure increased with increasing post-arterial cannula pressure, flow rate, and pulsatile amplitude. Physiologic-like pulsatility was achieved between pulsatile amplitudes of 2,000 and 3,000 rpm. Pressure drops were greatest across the arterial cannula, and the oxygenator was determined to have acceptable pressure drops (1.9–17.0 mmHg for neonatal circuit, 14.9–53.5 mmHg for pediatric circuit). THE increased at the pre-oxygenator site with increasing post-arterial cannula pressure and pulsatile amplitude. Post-arterial cannula THE increased with increasing post-arterial cannula pressure, pulsatile amplitude, and flow rate. There was no surplus hemodynamic energy (SHE) generated under non-pulsatile mode. Pre-oxygenator SHE increased with increasing post-arterial cannula pressure and pulsatile amplitude, but decreased with increasing flow rate.

Conclusion: The i-cor ECG-synchronized cardiac assist system is capable of providing non-pulsatile and pulsatile flow in neonatal and pediatric ECLS circuits. Pulsatile settings greatly impact the quality of pulsatility generated by the i-cor pump. It is recommended that pulsatile amplitudes of 2,000–3,000 rpm be used for neonatal and pediatric patients. Additional studies are needed to further characterize the pulsatile settings of this i-cor system for use in neonatal and pediatric ECLS.

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Health related quality of life in long-term survivors after treatment with extracorporeal membrane oxygenation (ECMO).

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BACKGROUND: Because ECMO treatment is increasingly used, better knowledge of long-term functioning and quality of life is essential.

OBJECTIVES: To describe Health Related Quality of life (HRQL) in all adult long-term survivors after ECMO treatment performed at the University Hospital North Norway.

MATERIALS AND METHODS: We obtained the data through a retrospective inquiry of the hospital's ECMO registry database for the years 1988–2015 and by a survey administered by mail (2016). The RAND Short Form-36 v1.2 was used to evaluate HRQL EQ-5D™ described activity limitations and employment status. Thirty survivors were identified. Twenty-three were eligible for inclusion after excluding children (2), foreign language/unknown addresses (3) and documented severe functional limitations (2).

RESULTS: The survey was completed by 20 (87%), 8 women (overall mean age 49, age range 23–81). Five had been on ECMO support for respiratory failure, 8 for cardiogenic shock (CS), 4 postcardiomyopathy heart failure (PCS) and 3 E-CPR (VV = 10%, VA = 90%). The average duration of ECMO treatment was 5 days (range 1–16 days). Sixty % (n=12) were treated between 2013–15.

Six years (average) after ECMO treatment 75% reported their mental or physical HRQL to be within the normal range (T= 50 +/-10) in comparison to age matched population data from national norms (Mental Component Summary mean 43, SD 5, range 34–51, Physical Component Summary mean 43, SD 4.5, range 34–53). The 7 survivors (mean age 51 (24–69), 4 men and 3 women) with at least one of the two component summary scores below the normal range (T<40) were all treated with VA ECMO on average 3 years before the survey for PCS=1, CS=5 or E-CPR=1.

Generally, the most frequent problems were detected on the SF-36’s subscales for General health and Role functioning. The subscales Physical functioning, Pain, Vitality, Emotional wellbeing and Social functioning were however within the normal range for the majority.

Ninety % lived independently in regular homes. Thirty-five % reported problems with walking, 10% problems with self-care and 40% problems with handling regular daily activities. Forty % were active workers, 20% retired, and 40% were on disability benefits.

CONCLUSIONS: In long-term survivors after ECMO treatment HRQL was encouraging but variable. The large majority were capable of independent living in regular homes. However, general health problems and activity limitations were frequently reported. An optimal rehabilitation program for these survivors needs to be developed in our follow-up care.

Poster or oral - either

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A challenging case of V-V ECMO
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30 year 24 weeks pregnant lady, previous cesarean section, diagnosed of upper respiratory tract infection and was treated for the same at an obstetric hospital. Breathlessness continued to worsen, and chest x-ray suggested –pneumonic consolidation in the left lung. Virology turned positive for H1N1.
In view of the worsening breathlessness, he was transferred to our centre for further help. At admission, her saturations were around 90%. She was started on Tamiflu and was given supportive therapy, inspite of which she continued to drop her saturations and was intubated and mechanical ventilation started. Her serial obstetric ultrasound confirmed the IUD, secondary to placental hypoxia.
In view of the IUD, and previous c-section, it was discussed that ECMO should follow evacuation of the dead fetus, which has to be medical termination, rather than surgical evacuation. Four days into the starting of medical termination, the dead fetus was evacuated.
She continued to worsen in terms of her respiratory illness, with significant drop in her blood oxygen saturations. Her chest x-ray worsened and now was involving both the lungs. She rapidly became hypoxic and had cardiac arrest. CPR was commenced and there was ROSC. The down time was for 6 min. The family was counselled and emergency V-V ECMO initiated. She gained consciousness after 24 hours without any neurological deficits.
She continued to progress with the recovery of the lungs, and enroute had iatrogenic bleed into left lung following repeated airway toileting, for which she had multiple flexible bronchoscopies and clot evacuation to recruit the left lung. She also developed HIT for which the circuit was run heparin free and received LMWH randomly. She progressed sufficiently, with single lung ventilation, at which time, it was decided to wean and come off the ECMO. Weaning was successful and decannulation was planned for the following day. In the interim night, she had accidental decannulation of the return cannula in the neck and lost output, during which she received 30 units of blood and blood products.
Decannulation was done the same night and was ventilated overnight after restoring the hemodynamics. She woke up after 24 hours with no neurological deficits.
She continued to progress and a CT scan lung was done to assess for the left lung, which fortunately was good, with patent airway and reasonable parenchyma.
She was discharged home after 56 days of ICU stay, 27 days on V-V ECMO, 179 units of blood and blood products.
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Coagulation for pediatric patients on ECMO: vWF and ADAMTS 13
Institution: Boston Children's Hospital
Background: Extracorporeal membrane oxygenation (ECMO) is a resource-intensive therapy for critically ill children. Managing anticoagulation on ECMO while balancing the risks of thrombosis and bleeding is a challenging task. vWF play a crucial role in hemostasis however data regarding the changes in HMW vWF during ECMO is limited in pediatric patients. The aim of this study is to understand the changes in ADAMTS 13, vWF level and activation during ECMO.
Methods: This is a prospective observational study approved by the IRB at Boston Children's Hospital. Data regarding cannulation, duration on ECMO, complications such as hemorrhage, thrombosis (clot formation, circuit change) and mortality is collected. vWF, vWF activation and ADAMTS 13 were measured. Continuous variables are described with means and standard deviations, categorical variables by counts and percentages. In the event of non-normality of the continuous variables, medians and inter-quartile ranges are used.
Results: Following IRB approval and parental consent, twenty patients with age 4days-14ears, median 11months; and 9 female/11male were recruited. The ECMO data included 4/20 veno-venous and 16/20 veno-arterial cannulations with 14/20 central and 6/20 peripheral (neck) cannulations. The prime was clear in 9/20 and blood prime was used in 11/20. The duration on ECMO ranged from 21–605 hours. ECMO complications included liver dysfunction (11/20), chest washout secondary to bleeding (7/20) and secondary to thrombosis (5/20), pulmonary hemorrhage (4/20), and bleeding at the surgical site (6/20). The mortality within 30 days was 5/20 and ECMO survival to discharge was 9/20.
The median blood requirements on ECMO were packed red blood cells 234ml/kg, fresh frozen plasma 179ml/kg, platelets 57ml/kg and cryoprecipitate 5ml/kg. The vWF levels positively correlated with vWF activation. (Figure 1A). In addition, the vWF activation positively correlated with ADAMTS13 level. (Figure 1B).

Discussion: In this study, HMW vWF correlated positively with vWF activation. And vWF activation was higher than normal value in this population. This result is in contrast with previous adult studies where low vWF activation levels were noted on ECMO. Multiple factors may contribute to this result including the difference in coagulation profile between pediatric and adults, the ECMO circuit size and the amount of blood products transfused to children on ECMO. Future analysis includes correlation of the TEG values and clinical outcomes with the measurements of ADAMTS 13, vWF level and activation.
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Plasma Arginine and Urea Cycle Intermediates in Pediatric Patients Requiring Extracorporeal Membrane Oxygenation (ECMO and CPB)
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Introduction: Patients undergoing extracorporeal membrane oxygenation (ECMO) or congenital heart surgery with cardiopulmonary bypass (CPB) are at risk of multisystem organ dysfunction associated with endothelial dysfunction and impaired systemic oxygen delivery. Arginine is an essential amino acid and precursor of nitric oxide (NO), and depletion may have deleterious effects. The aim of this study is to investigate the profile of arginine and urea cycle intermediates, and arginase in infants and children on ECMO or after CPB.

Methods: Prospective study in children undergoing cardiac surgery with CPB or on ECMO (for respiratory or cardiac support) at a tertiary pediatric hospital. Serial blood samples were obtained prior to, and at 90 min, 6h, 12h, 24h, 48h and 5 days after initiation of CPB or ECMO. Samples were analyzed for amino acid quantification (arginine, ornithine, citrulline, glutamine), and arginase levels.

Results: Thirty CPB patients aged 1.9 (3.2) years and 22 ECMO patients, aged 3 (4.7) years were included in the study. In patients undergoing CPB, arginine levels fell over the first 24 hours (P<0.01), and arginase increased concomitantly (P<0.05), with recovery towards baseline thereafter. In ECMO patient’s arginine levels progressively increased despite higher arginase levels in comparison to the CPB cohort. Ornithine concentration followed a similar pattern as arginase. Citrulline fell after CPB (P < 0.01), with a similar trend (P < 0.096) in ECMO patients. Likewise, CPB was followed by a decrease (P < 0.01) in plasma glutamine concentration whereas in ECMO, patients had lower glutamine concentration since the initiation of the circuit and did not change throughout the observation period.

Conclusion: In this pilot study, arginine, citrulline and glutamine depletion occurred in the first 48 hours after CPB, coupled with a significant increase in arginase. This could indicate an association with the known fall in systemic oxygen delivery (a low output state) that is commonly observed in these patients. Glutamine depletion that affected ECMO patients could indicate a loss of integrity of the intestinal mucosal barrier. Understanding the profile of urea cycle intermediates in these patients could lead to the identification of new pathways for therapeutic interven-

Successful outcome of a patient treated with 5 different cardiac devices after cardiogenic shock due to myocardial infarction
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Abstract
Mechanical circulatory support (MCS) devices play important role in modern heart failure treatment and intensive care medicine. We present the case of a 42-year-old male patient who was admitted to an outside hospital with severe chest pain and shortness of breath. He was taken to the catheter laboratory and was found to have an occlusion of his left anterior descending (LAD) coronary artery. Balloon angioplasty was performed on this lesion but no stent was deployed. Despite reopening of the culprit lesion the patient remained in cardiogenic shock and was first supported with an intra-aortic-balloon pump but shortly thereafter with veno-arterial extracorporeal membrane oxygenation due to unresolved shock.

Over a course of almost two weeks the patient’s cardiac function (LVEF) recovered from initially 15% to finally 40%. On day 6 he was tested HIT positive after he had developed severe thrombocytopenia. On day 12 as a result of a multidisciplinary decision the patient was again taken to the catheter laboratory, now for a definite treatment of his coronary lesions with drug-eluting stents. Two days later he was successfully weaned from veno-arterial extracorporeal membrane oxygenation.

The second day after he was weaned from extracorporeal membrane oxygenation the patient cardiac arrested but could be successfully supported with veno-arterial extracorporeal membrane oxygenation after 45 minutes of resuscitation. He was again taken to the catheter laboratory where he was found to have an in-stent restenosis of the LAD stent. The stenosis could be opened but the patient remained in severe pulmonary edema and therefore an Impella CP® was placed to help with left ventricular unloading.

Unfortunately, the patient’s left ventricular function did not recover from this second incident and after a period of organ recovery the patient was transitioned from ECMO to a left ventricular assist device (LVAD). Post LVAD implant he required temporary right ventricular assist device (RVAD) support for transient right heart failure.

At day 99 after his admission he could be discharged to a rehabilitation facility ambulating with support, no neurological disorders but still requiring hemodialysis. After 19 days at the rehabilitation facility he could be discharged to home with improving renal function.

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Figure 1: Mean concentration of arginase, arginine, citrulline, glutamine over time in ECMO and CPB cohort; * p<0.05 (comparison with time 0)

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Is PEA a reason to refuse ECPR?
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**Background:** CPR with extracorporeal membrane oxygenation support (ECPR) has shown to improve outcome in patients after cardiac arrest under resuscitation. Most current recommendations for ECPR do not include patients with a non-shockable rhythm such as PEA and asystole, and do not differ between the PEA and asystole.

**Aim:** The aim of this study was to investigate and compare the outcome of the 3 different patient groups separated due to initial rhythm at time of placing on ECMO: asystole, PEA and shockable rhythm.

**Methods:** We made a retrospective single-center study of adults who underwent ECPR for in-hospital cardiac arrest between June 2008 and January 2017. Outcome and survival were identified in 3 different groups of patients: 1. patients with asystole, 2. patients with pulseless electrical activity (PEA), 3. patients with a shockable rhythm (ventricular tachycardia or ventricular fibrillation) at the time of decision to place on ECMO.

**Result:** 63 patients underwent ECPR in the mentioned time frame. 5 patients were excluded due to missing data. Under the 58 included patients the number of cases for asystole, PEA, shockable rhythm was 7, 21 and 30 respectively. The means CPR-time in these groups were 37, 41 and 37 minutes. Survival to discharge was 0.0%, 23.8% and 40.0% respectively (p=0.09). All survivors to discharge had a good neurological outcome, defined as cerebral performance category (CPC) 1 or 2.

**Conclusion:** Survival to discharge in patients with PEA as initial rhythm at the time of decision for ECPR is 23.8% while no patients with asystole as initial rhythm survived discharge. PEA alone should not be an exclusion criterion for ECPR while patients undergoing ECPR with asystole have a very poor outcome.

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Nitrogen balance during veno-venous ECMO support – preliminary results of a prospective, observational study
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**Background:** Research has established that tolerance to enteral nutrition during extra-corporeal membrane oxygenation (ECMO) is similar to that of general ICU patients. However, current literature is insufficient to support specific guidelines for estimating nutritional needs during ECMO. Guidelines for general critical illness state that protein appears to be the most important macronutrient and recommend a range of 1.2–2 gm/kg/day actual body weight for normal-weight patients, with adjustments for obesity. The purpose of this study is to describe the degree and duration of protein catabolism during ECMO support, and to assess if providing protein according to current guidelines for critical care is adequate to achieve nitrogen equilibrium in these patients.

**Methods:** All patients admitted to the Lung Rescue Unit (LRU), a multidisciplinary critical care unit dedicated to providing care for patients on veno-venous ECMO (VV ECMO) between11/2016 and 6/2017 were screened for eligibility. As part of the LRU’s standard practice, all patients are assessed by a Registered Dietitian (RD) within 2 days of admission. The RD estimates protein needs of 1.5–2 gm/pro/kg for normal weight patients with adjustments for obesity. Once patients tolerate goal nutrition support a 24-hour urine urea nitrogen (UUN) is collected and analyzed for nitrogen balance (NB) assessment using the following formula: [gm Pro in x 6.25] – [(24 hr urine urea nitrogen + 0.85) + insensible losses].

Nitrogen equilibrium is defined as -2 - +2 per institutional practice. Serial monitoring of NB continues on a weekly basis until patients are decannulated from VV ECMO, reach ECMO day 45, or no longer have a reliable method of urine collection. Nutrition support is adjusted based on the weekly NB results. Demographics, ECMO specific data, NB results, nutrition orders, and nutrition received were recorded in a prospective observational manner.

**Results:** Sixteen patients were enrolled during the study period with a total of 25 NB studies collected. Mean age was 37 ± 11 years, mean body mass index (BMI) was 33 ± 10 and 10 (62.5%) were male. Non-obese (BMI < 30) patients received 86% of their prescribed mean protein dose of 1.82 ± 0.25 gm/kg actual body weight (ABW). Obese (BMI ≥ 30) patients received 82% of their prescribed mean protein dose of 2.5 ± 0.3 gm/kg ideal body weight (IBW). Eleven measurements were collected in 6 non-obese patients and fourteen measurements in 10 obese patients. Non-obese patients had a mean NB of -1.7 ± 5.7 while obese patients had a mean NB of -11.5 ± 9.6. Obese patients had a significantly higher UUN (26.7 +/- 7.7 vs 13.5 +/- 4.3, p 0.00004).

**Conclusion:** This preliminary data suggests that current guidelines for estimating protein needs in critically ill patients may be adequate to meet demands of non-obese patients on VV ECMO. However, based on our preliminary data, obese patients have significantly higher rates of catabolism as measured by UUN while on VV ECMO and current nutritional guidelines for this critically ill patient population may not be adequate. Future studies with a large cohort of patients are needed to confirm these preliminary results.

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Oral or poster presentation
CASE REPORT: FORMER 23 WEEK INFANT THAT EXPERIENCED ACUTE RESPIRATORY FAILURE AFTER RETINOPATHY OF PREMATURITY (ROP) SURGERY THAT REQUIRED EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO). BETTY PERRY MBA, RRT-NPS, HEIDI WHITE B.S., RRT-NPS and MATTHEW LEDOUX, MD Vidant Medical Center, Greenville, North Carolina.

Introduction: A former 23 week infant, that is now three months old, that was diagnosed with Bronchopulmonary Dysplasia (BPD) was taken to the Operating Room (OR) for stage 3 ROP surgery. Patient was then transferred to the Neonatal Intensive Care Unit (NICU) post-operative for ventilator management. Patient experienced acute respiratory failure and required transfer to the Pediatric Intensive Care Unit (PICU) for ECMO.

Case Study: Patient was admitted to the NICU as 23 week premature infant that received positive pressure ventilation and chest compression in the delivery room. Patient was intubated and given surfactant and placed on the high frequency oscillator for ventilation management. Patient remained ventilated for 3 months when the patient was extubated to nasal continuous positive pressure ventilation and then transitioned to high flow nasal cannula. Patient was then intubated for eye surgery in the OR. Patient tolerated surgery well. Upon arrival to the NICU the patient was somnolent and riding the ventilator. Patient initially had acceptable capillary blood gases but within six hours the patient was in a respiratory acidosis with worsening chest radiographs. Patient had acute decompensation and hypoxia secondary to possible sepsis/septic shock with metabolic acidosis, with white blood cell count of <5 and CRP of 150. Patient was transferred to the PICU for ECMO cannulation and management. Patient was cannulated and placed on venoarterial ECMO support on approximately 85% of cardiac output. Patient’s ECMO course was complicated by coagulopathies that required blood products to attain normal values. Patient was ventilated with the high frequency oscillator and within 5 days was able to be weaned to conventional ventilator on rest settings. Patient was given a dose of surfactant while on ECMO to aid with lung recruitment and expansion. Patient was decannulated on day 8 of ECMO. Patient still had a complicated hospital course that required a tracheostomy and G-Tube. Patient was able to be discharged 297 days ventilator and tube feeding dependent but with a good neurologic outcome.

Discussion: This patient was a former 23 week premature infant that develop BPD but was able to be extubated and was stable on high flow nasal cannula for several weeks prior to going to surgery for ROP stage 3 repair. The patient then developed acute decompensation that resulted in the patient being placed on ECMO for survival.

Conclusion: A patient with known BPD and a history of prematurity may be a good candidate for ECMO even with existing lung disease. Should they decompensate weeks after birth and all other inclusion criteria for ECMO are met consideration for cannulation should be considered. These patients should be carefully selected and a complicated and potentially longer course should be anticipated but a good neurologic outcome is possible.

Speckle-tracking echocardiography in patients undergoing extracorporeal life support
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Background
Extracorporeal membrane oxygenation (ECMO) and other types of extracorporeal life support (ECLS) strategies are increasingly used in the critically ill patients in case of refractory respiratory and/or cardiac failure. These patients are particularly prone to develop new or further cardiac abnormalities. Although echocardiography has been recently acknowledged a crucial role in the management of patients on ECLS, clear guidelines on which echocardiographic parameters should be monitored are not available. Recently, strain measurement with speckle-tracking echocardiography (STE) has emerged as a more sensitive marker of intrinsic myocardial contractility and outcome predictor than traditional echocardiography (TE), particularly in sepsis and pulmonary hypertension. The aim of this study was to: 1) report the utilization of echocardiography in patients supported with ECLS; 2) assess the feasibility of STE; and 3) evaluate the reproducibility of TE and STE.

Methods
The clinical and echocardiographic data of all patients supported with ECLS at our Institution since 2014 were collected. Biventricular strain was measured offline with the speckle-tracking technique using a commercially available software package. Three investigators assessed the image quality for strain measurement eligibility and performed the STE. The correlation and agreement between the echocardiographic measurements determined by TE and STE were evaluated with linear regression analysis, Bland-Altman plot, and Pitman’s test of difference in variance. P-value < 0.05 was considered statistically significant.

Results
ECLS was required in 126 patients, 69 patients in 2014 and 57 in 2015. Echocardiography was performed in 60 patients in 2014 and 54 in 2015. The total number of echoes completed was 491: 95 exams were carried out before cannulation, 300 between cannulation and decannulation, and 96 after decannulation. Of these, 433 exams (88.2%) were deemed to be traceable for STE, which was performed in 14 patients: ten patients received veno-arterial ECMO, 3 patients veno-venous ECMO, and 1 patient Impella®, for a mean duration of 15 days. The linear regression analysis revealed a moderate to strong correlation for most echocardiographic measurements between TE and STE. The Bland-Altman analysis and the Pitman’s test of difference in variance showed that 5 variables (end-systolic left ventricular internal diameter, left ventricular mass, right ventricular internal diameter, tricuspid annular plane systolic excursion, and right ventricular S’ wave) were significantly overestimated by TE as compared to STE, whereas 2-chamber left ventricular end-diastolic volume was significantly underestimated. The two methods agreed on the other 9 measurements.

Conclusion
Echocardiography was frequently performed in patients supported with ECLS at our Institution. STE was feasible and moderately agreed with TE in the main echocardiographic measurements. Further results from the current study are needed to understand whether STE represents a potentially useful technique in the management of this high-risk population of patients. Notably, the availability of online STE analysis may allow the prospective evaluation of STE in the hemodynamic and respiratory care of these patients.

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The use of extra-corporeal membrane oxygenation in a pediatric patient with hepatopulmonary syndrome and interrupted inferior vena cava after living related liver donation

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Introduction: Extracorporeal membrane oxygenation (ECMO) is used for severe cardiac and/or respiratory failure. Hepatopulmonary syndrome (HPS) occurs in the setting of liver failure, causing overproduction of pulmonary vasodilators, intra-pulmonary shunting, and abnormal gas exchange due to vasodilation of the pulmonary vessels. Additionally, pulmonary angiogenesis occurs and contributes in addition to the effect of the pulmonary vasodilators to contribute to HPS. Hepatopulmonary syndrome can lead to severe hypoxemia either before or after liver transplant, and has been shown to be associated with a poor prognosis. Liver transplantation is the only curative intervention. Previous case reports in adults and children have described the use of ECMO support for HPS, we demonstrate the use of a double lumen veno-venous cannula for HPS in a child with an interrupted IVC, and who had a normal neurologic outcome following her ECMO run.

Case: This is a 19-month old female with a history of biliary atresia who underwent a Kasai portoenterostomy at 119 days of life. She continued to develop signs of liver failure and was referred to our transplant center for evaluation. At that time, she required high flow nasal cannula at 8L and 80% FIO2 to keep her oxygen saturation >80% prior to living related donor liver transplantation, but was otherwise deemed an appropriate candidate for transplant. She underwent living related liver transplantation which was complicated by severe hypoxemia post-transplant, which was refractory to conventional ventilation, PEEP >16, FIO2=100%, INO=20PPM, epoprostenol, methylene blue. She demonstrated labile oxygen saturations from the 50’s to the 80’s. The decision was made to place the patient on veno-venous (VV) ECMO using a 16-French double lumen right IJ cannula. The patient was supported with VV ECMO for a total of 17 days. We had minimal problems with recirculation, but the ECMO run was complicated by bleeding from the transplanted liver. The bleeding was managed with interruption of heparin and lowering our therapeutic heparin targets. Following decannulation, the patient remained intubated for an additional 2 days, and was extubated to high flow nasal cannula, and weaned to room air over the next 2 weeks.

Discussion: While previous studies have demonstrated the use of ECMO in post-transplant adult patients, this is only the second pediatric patient we could identify in the literature. This case is unique in that the patient had an interrupted IVC, and while the other patient was cannulated via the right internal jugular and femoral vein, this may not have been possible in this patient. This was accomplished with minimal recirculation, and provided sufficient flow to support the patient during a 17-day ECMO run. Post-transplant ECMO may provide patients with HPS and severe post-transplant hypoxemia a period of support for their pulmonary vessels to remodel and allow for recovery from HPS.

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ECMO Management of Infants of Diabetic Mother with Persistent Pulmonary Hypertension of Newborn (PPHN) and Obstructive Hypertrophic Cardiomyopathy – A case series

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Background: Extracorporeal membrane oxygenation (ECMO) is currently the standard of care for neonates to manage cardiopulmonary failure refractory to medical therapy. Abnormal glucose control is present in 3–10% of all pregnancies in the United States. Infants of diabetic mother (IDM) present with wide spectrum of congenital anomalies. They often develop respiratory problems which need to be differentiated from the cardiovascular problems they are prone to have, namely structural congenital heart defect and hypertrophic cardiomyopathy (HCM) and from cardiovascular maladaptation to extra-uterine life. ECMO has been used as an adjunct therapy in these infants while concurrently treating hypertrophic cardiomyopathy. Apart from individual case reports, there are no set guidelines on management of IDM infants with HCM and left ventricular outflow tract obstruction (LVOT) requiring ECMO.

Objective: Present a single center case series of four IDM neonates who presented with PPHN as well as HCM with LVOT obstruction requiring ECMO.

Study design: This is a descriptive study, presenting the course of 4 term neonates delivered to mothers with diabetes transferred to the neonatal ICU at Augusta University from April 2016 to present for management of PPHN and circulatory support. All four received ECMO for respiratory and/or circulatory support. Two received Veno Venous ECMO (VV ECMO) and two received Veno Arterial ECMO (VA ECMO). The shortest run was 4 days and the longest run was 29 days. The common elements in the four cases form the basis of these guidelines.

Results: All 4 patients in this series had HCM with septal hypertrophy causing varying degrees of LVOT obstruction. Standard therapy guidelines for PPHN apply including ventilation, nitric oxide, sedation/paralysis. Specific guidelines related to HCM with outflow tract obstruction include:

a. Biventricular and septal hypertrophy are expected which can result in diastolic dysfunction and raises risk of circulatory compromise with traditional pressors. Therefore traditional pressors are avoided with preference to dobutamine or milrinone due to reduced chronotropic effect.

b. One of the mainstays of therapy is beta blockade. Start Esmolol drip early for heart rate and blood pressure control. Starting from 50 mcg/kg/min to 300 mcg/kg/min. Increase in step wise fashion.

c. Esmolol does provide large fluid volume. If high doses of beta blockade is required, can switch to Propranolol as it is longer lasting and smaller volume.

d. The degree of left ventricular outflow tract (LVOT) obstruction determines type of ECMO. VA ECMO being preferred when the LVOT obstruction is moderate to severe.

e. Start hemodialysis early to maintain acid-base and electrolyte balance.

f. Unlike traditional ECMO, maintain euvolemic status. Prevent under filling of ventricles given the cardiac anatomy.

g. Multidisciplinary approach involving cardiology, nephrology and pediatric surgery.

Conclusions: Recent query of ELSO has revealed only one patient with PPHN and HCM with LVOT obstruction who passed away. To our knowledge this is the first set of guidelines for management of an IDM baby with PPHN and HCM with LVOT obstruction. All four of our patients were successfully weaned from ECMO and discharged home. We acknowledge that this is an observational study and a single center experience.

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Adherence to a Mechanical Ventilation Protocol in Pediatric Patients Requiring VV-ECMO

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INTRODUCTION: In children requiring VV-ECMO significant variability in mechanical ventilation practices exist. To standardize lung management and avoid ventilator-associated lung injury, the VV-ECMO lung algorithm (VELA) was implemented in 2013 at our institution. This algorithm emphasizes pressure control mode while limiting peak inspiratory pressures ≤ 25 cm H2O. The objective of our study was to describe the adherence to and impact of VELA.

METHODS: We conducted a retrospective cohort study of patients (1 month-18 years) requiring VV-ECMO from January 2012 to July 2016. Any deviation from ventilator setting recommendations outlined in the algorithm was defined as non-adherence. Patient outcomes were compared between pre- and post-VELA groups and analyzed with Fisher’s exact test and chi-squared tests.

RESULTS: Of 25 patients, 14 and 11 were hospitalized pre- and post-VELA implementation, respectively. The most common admission diagnosis was acute respiratory failure. Baseline characteristics of pre- v. post-VELA patients included: mean age (years) (5.8 v. 3.9), female (36% v. 55%), pre-maturity (29% v. 18%), and underlying lung pathology (56% v. 36%). Use of high frequency oscillatory ventilation, nitric oxide, vasopressors, and corticosteroids was similar between groups. Adherence to VELA was 27%, and non-adherence was most commonly due to utilization of volume control mode (82%). However, average peak inspiratory pressures were limited to ≤ 25 cm H2O in pre- and post-VELA groups for the first five days of VV-ECMO. Compared to pre-VELA, patients post-VELA trended toward decreased mortality (29% v. 18%, p=0.66), fewer median days of ECMO (10.3 v. 6.8, p=0.06), fewer median days in the PICU (23.5 v. 18.0, p=0.49), and a shorter median hospital length of stay (39.5 v. 25.0, p=0.41).

CONCLUSIONS: Although adherence to VELA was low, peak inspiratory pressures were appropriately limited. Our study was underpowered to detect statistically significant differences despite a trend of decreased mortality, and fewer ECMO, PICU, and hospital days in post-VELA implementation patients. Further study is needed to guide future modifications and determine the impact of this algorithm.

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ECMO for Hypoxic ischemic encephalopathy in neonates: Differences in attitudes between Neonatologist and Non – neonatologists

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Introduction: Term neonates with moderate to severe HIE treated with therapeutic hypothermia (TH) have a 10-25% incidence of pulmonary hypertension. A small percentage of these patients need ECMO for respiratory failure even though the long-term outcomes have not been evaluated. Similarly the attitudes regarding ECMO and HIE are not recently reported. The initial results were presented at the 2016 ELSO conference as “Survey of ECMO practices in infants with hypoxic ischemic encephalopathy”. This abstract focuses on the differences noted in the responses between neonatologists and non-neonatologists in the survey.

Methods: A 22 question electronic survey was sent to the neonatal medical director of the 97 neonatal-perinatal training programs and to the ECMO director at the 132 neonatal respiratory ECMO centers in the United States and Canada.

Results: We collected 89 responses representing 68 of 149 invited institutions (46%). Participants were self-described as 53% ECMO director, 57% NICU director, and 15% both. Neonatologists were more likely to offer ECMO for HIE patients with mild and moderate HIE and nearing significance for severe HIE (figure 1). They were also less likely to pay attention to cord pH or base deficit for deciding eligibility for ECMO. Neonatologists were more likely to accept severe neurodevelopmental delay as an acceptable outcome for neonates with HIE treated with ECMO than non-neonatologists. However both neonatologists and non-neonatologists have similar perceptions of acceptable outcomes for patients with moderate, profound NDD and chronic ventilation.

Discussion: Important differences in practice among practitioners were identified from the survey. In general the neonatologists were more likely to offer ECMO for HIE patients with higher tolerance of worse outcomes. They were also less likely to consider cord pH and base deficit during ECMO selection. It is likely that exposure to improved outcomes in HIE patients after introduction of TH and the lack of a validated tool for predicting long term outcomes of HIE patients has led to lower threshold for use of ECMO amongst neonatologists. It is essential to study the long-term outcomes to better define ECMO eligibility criteria for HIE patients.

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Clinical Predictors of Safety and Efficacy of Veno-Venous Extra-Corporeal Life Support

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Objective: This study assesses clinical and demographic factors from The Ohio State University Wexner Medical Center Veno-Venous Extra-Corporeal Life Support (VV-ECLS) Guidelines that affect in-hospital mortality in patients treated with veno-venous extracorporeal membrane oxygenation (VV-ECMO).

Background: The Ohio State University Wexner Medical Center established hospital-wide guidelines for initiating VV-ECLS treatment in patients with severe acute respiratory failure in 2014. The effect of these guidelines on patient survival has yet to be assessed.

Methods: The cohort included 45 patients (mean age 45 years, 64% male) who were treated with VV-ECMO between 2013 and 2016. The association of in-hospital survival to age, weight, contributing chronic disease, refractory respiratory failure less than 7 days, other mechanical and medical causes to survival, PEEP, and number of diseased quadrants of chest x-ray was examined using regression analysis. The outcomes of patients treated with VV-ECMO in 2013 before the establishment of hospital guidelines (n = 6) were compared to outcomes of patients treated with VV ECMO between 2014 and 2016 after the hospital guidelines were established (n = 39).

Results: Clinical and demographic predictors of survival to decannulation and survival to hospital discharge were determined using logistic regression. Thirty-four patients (76%) survived on VV-ECMO until decannulation, and of these patients twenty-eight patients (82%) survived until they were discharged from the hospital. The survival rate to decannulation increased over the time period from 2013 to 2016 with survival rates of 50% in 2013, 69% in 2014, 85% in 2015, and 85% in 2016. In hospital survival was found to be positively associated with patients placed on VV ECMO who were younger in age (p = 0.0125), had no chronic disease (p = 0.012), had a higher PEEP (p = 0.0225), and had been in refractory respiratory distress for less than 7 days prior to initiation of VV ECMO (p = 0.0271).

Conclusions: Since the induction of the hospital-wide guidelines for initiating VV-ECLS treatment in patients with severe acute respiratory failure in 2014, the survival of patients placed on VV ECMO at The Ohio State University Wexner Medical Center has increased from 50% to 85%. These findings suggest a role for patient selection for initiation and decannulation of VV ECMO, especially pertaining to patients who are older, have concomitant chronic diseases, and are suffering from refractory respiratory failure for more than 7 days prior to initiation of VV ECMO.

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Can ECMO facilitate a more conservative management strategy in lung abscess?

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Background
Lung abscess is a rare but serious complication of pulmonary infection. It is more likely to occur in patients with underlying lung disease or other severe co-morbidities affecting their immune response. Management is complex, ranging from antibiotic therapy to pneumonectomy in some cases. Patients requiring ECMO are more likely to fulfill the indications for surgical resection in this condition.

Cases
Our institution has recently treated two patients on ECMO with septic shock secondary to pneumonia complicated by large lung abscesses. Both patients are female and in their first decade. The first had a history of previous pulmonary tuberculosis and alcohol excess. She went on to minimally invasive drainage as a means of source control. The second had no significant past medical history and to date is recovering with conservative treatment. Both have been successfully weaned from ECMO support.

Discussion
Both cases had complex abscesses that could have required extensive lung resection. ECMO provided a platform for prolonged antimicrobial therapy and potentially reduced the risk of complications such as cavity rupture. Additionally, if this approach had failed surgical resection would have still been an option with the support of ECMO. This would not have been possible with a patient supported by mechanical ventilation only.

References

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ECMO Specialists’ Perceived Barriers to Pediatric Mobility
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Background: Mobilization of critically ill patients, including patients on ECMO support, occurs across a continuum of activity and often starts with implementing frequent patient turning. Frequent turning is a vital practice used to facilitate mobilization of respiratory secretions and is the primary intervention used to mitigate risk of pressure injury development. ECMO patients present additional challenges to frequent patient turning such as cannula movement, fear of accidental decannulation, and cannula site bleeding. Cephalad cannulas have the additional challenges of maintaining adequate flow with changes in head position. The smaller the patients are, the higher the perceived risk of complications. Though pediatric ECMO patients have added vulnerabilities, turning and repositioning remain important aspects of care to promote mobilization. Little evidence is available in the literature on how to best turn and reposition pediatric ECMO patients, the relation of position to pump flow, and rates of position related complications, making it difficult to use data to inform our care practice.

Objective: To determine the current practice and barriers to turning pediatric ECMO patients at our center.

Methods: A survey to gauge practice and perceptions of ECMO specialists was implemented to look at turning and repositioning ECMO patients at our center. The study was approved by the IRB and guidelines for the study implementation outlined. An anonymous survey was distributed to ECMO specialists to assess perception of turning practice across several variables. Descriptive statistics are presented.

Results: We had an 89% response rate to the survey sent to 48 ECMO specialists (n=43). 18% of specialist reported the desire for more information about safe turning and repositioning of ECMO patients. 39% (n=17) reported moderate or higher levels of concern or anxiety about repositioning ECMO patients. 55% report being comfortable with turning and repositioning these patients. 49% rated task prioritization as high or essential. A turn frequency of 1 to 3 times a shift was reported in 72% of responses and turning was described as sight turns to offload pressure in a majority of responses (n=26/60%). High task prioritization rating, lack of discomfort, and a rating of mild or absence of anxiety or concern was associated with higher likelihood that turning was described as exceeding slight turns to offload and that turning frequency was ≥3 times a shift.

Conclusions: Survey responses support presence of significant concern or anxiety about turning and repositioning ECMO patients approaching 40%. Overall, the survey findings support the need to evaluate this important care practice and collect data with a goal of providing a source of information to help guide practice. Additional studies are ongoing at our center to evaluate the complications actually seen during repositioning and will be reported in the future.

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Use of FEIBA in the Setting of Massive Postoperative Hemorrhage in a Pediatric ECMO Patient
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Case Description: A 10 year old female with complex congenital heart disease, interrupted IVC with axugous continuation to right SVC, and bilateral SVC s/p Kawashima Fontan, hepatic vein to axugous vein shunt, and dual chamber pacemaker presented after cardiac arrest secondary to polyomorphic ventricular tachycardia. The patient subsequently required intracardiac defribillator placement via redo sternotomy. On the fourth post-operative day the patient developed progressive cardiorespiratory failure and was cannulated via femoral cannulation for VA ECMO. Insufficient ECMO flow necessitated central cannulation with cannulas connected into the existing femoral cannulas; ECMO flows of approximately 5L/min were achieved. To preemptively address the risk of bleeding in a patient s/p multiple sternotomies, an aminocaproic acid bolus of 100 mg/kg followed by an infusion of 10 mg/kg/hour was initiated prior to central cannulation. Despite this measure, the patient developed massive hemorrhage (chest tube output 20–30 mL/kg/hr), which persisted despite discontinuation of heparin infusion and surgical exploration. Measures of hemostasis included fibrinogen 183–294 g/dL, platelet count 99,000–107,000/μL, unfractionated heparin <0.10 IU/mL, INR 2.1, PTT 39.8 seconds, and normal thromboelastography. The patient received 3 doses of recombinant activated Factor VII (6 mg) approximately 1 hour apart. The bleeding improved (chest tube output 10 mL/kg/hr) but was persistent. FEIBA was given (1110 units) and chest tube output abruptly declined to 1–2 mL/kg/hr. No circuit or patient thrombosis was noted. Traditional unfractionated heparin anticoagulation was resumed and measures of anticoagulation were maintained within target range. On ECMO day 6, the patient developed a spontaneous intracranial hemorrhage requiring withdrawal of ECMO support.

Discussion: Factor VIII inhibitor bypassing activity (FEIBA) contains nonactivated therapeutic levels of factors II, IX, X and mainly activated factor VII. This is the first report of the use of FEIBA in a pediatric ECMO patient. The use of FEIBA and activated FVII in a 56 year old patient on ECMO which resulted in massive intracardiac and circuit thrombosis has been reported1.

FEIBA should be used with caution in patients who have prothrombotic risk factors including disseminated intravascular coagulopathy. It is known that exposure of blood to the artificial bypass circuit in ECMO induces DIC. Use of FEIBA in patients receiving concomitant activated Factor VII portends an increase in thrombotic risk secondary to an increase in circulating tissue factor. Given the large volume of hemorrhage and half-life of activated FVII it is likely, in this patient, that the activated FVII was no longer present at the time of FEIBA administration. In addition, the use of FEIBA in conjunction with antifibrinolytic agents may exacerbate the prothrombotic effects of FEIBA. Fortunately, our patient did not experience a significant thrombotic event. In this patient, massive hemorrhage led to massive blood product replacement (approximately 11 L). Despite this, fibrinogen, platelets, and markers of hemostasis were normal. While antithrombin III was not measured, it is likely that it was in the normal range given the large amounts of transfused fresh frozen plasma. In addition, the high flow rate of 5L/min likely prevented significant stasis of flow thus preventing thrombus formation. Further investigation into the safety of activated prothrombin complex concentrates in ECMO patients is warranted. In our patient, concomitant use of activated Factor VII, antifibrinolytic, and FEIBA allowed for resolution of massive hemorrhage without thrombotic complications.

Creation of a pharmacokinetic model for optimal initial heparin dosing in pediatric patients receiving extracorporeal membrane oxygenation
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Institution: Primary Children’s Hospital

Purpose: Heparin is the anticoagulant most frequently used for pediatric patients receiving extracorporeal membrane oxygenation (ECMO). However, a paucity of data exists analyzing the rate of heparin administration and the time for patients to reach therapeutic anticoagulation. By minimizing the time to therapeutic anticoagulation, it is hypothesized both patient outcomes and ECMO outcomes may be improved. Our goal is to create and validate a pharmacokinetic model for initial heparin rates in pediatric patients to decrease time to therapeutic anticoagulation and reduce thrombotic complications associated with ECMO.

Methods: The Institutional Review Board at Primary Children’s Hospital approved this retrospective, observational study. Patients were included if they were admitted to Primary Children’s Hospital for ECMO with heparin anticoagulation from January 1, 2012 to December 31, 2016. Patients on ECMO for <24 hours or with incomplete medication charts were excluded. Data collected includes patient demographics, laboratory values associated with anticoagulation, medication data including all heparin rates and rate changes, serum creatinine, length of stay, mortality, major bleed, type of ECMO, and ECMO circuit outcomes. These data will be used to determine the optimal initial heparin infusion rate based on patient specific factors.

Results: A total of 139 patients were identified for inclusion in the pharmacokinetic model. 46.7% cannulated to veno-venous (VV) ECMO and 53.2% cannulated to veno-arterial (VA) ECMO. The majority of patients were <30 days old, male, and Caucasian. Overall mortality was 32.3%, 29% for age <30 days cannulated VV, 3.7% for ≥30 days cannulated VV, 33% for age <30 days cannulated VA, 52.3% for age ≥30 days cannulated to VA. Overall risk of major bleed was 0.056 bleeds per day of ECMO (approximately 1 bleed every 20 days of ECMO). Bleeding rates were much higher for VA patients with a rate of 0.1 major bleeds per day of ECMO. Percent time at therapeutic anticoagulation based on age, ECMO circuit outcomes as related to anticoagulation markers, and final pharmacokinetic model will be presented.

Conclusions: To be presented

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Ultrasound Use for ECLS Cannula Position in Children: Avoiding pitfalls in difficult situations
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Purpose: Malposition of cannulas during extracorporeal life support (ECLS) can result in loss of flow, recirculation, hemodynamic compromise, and complications to major blood vessels. In certain situations, however, the cannula position cannot be confirmed using standard techniques of x-ray and/or fluoroscopy. We describe our experience with ultrasound use in such situations to help determine the location of the cannula tip and avoid complications.

Methods: We retrospectively reviewed electronic health records, including radiographic images for children managed with ECLS at our institution over the past year. All cannulations were performed either at the bedside or in the operating room with x-ray and/or fluoroscopic guidance to confirm tip position. However, in some children, contraindications to use of contrast, clinical instability, lack of appropriate anatomic landmarks or inability to see the catheter on standard radiology images, required the use of ultrasound to avoid further complications and more accurately assess tip positioning. We describe 5 such cases where bedside ultrasound use was crucial to appropriate management on ECLS.

Results: All 5 children required ECLS for pneumonia, pulmonary hypertension, or other pulmonary indications. One patient had a documented dye allergy, two patients had known congenital diaphragmatic hernias with altered anatomy on radiographs, and the other two were hemodynamically unstable with inability to see the cannula tip due to radiolucency. In each patient, the ultrasound use helped guide the catheter tip to appropriate position at the bedside. There were no complications involving catheter tip malposition during the hospital course.

Conclusions: Ultrasound use is a safe, convenient, and efficient way to check cannula position and help reposition ECLS catheters at the bedside, especially when conventional approaches are unsuccessful.

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A 62 year-old male with Stage III Chronic Kidney Disease was diagnosed with aortic valve infective endocarditis and treated with intravenous antibiotics at an outside hospital. One day after discharge, he presented to the emergency department with an anterior STEMI. An echocardiogram revealed: reduced left ventricular ejection fraction of 10 to 15%, aortic valve vegetation and moderate aortic insufficiency. He was transferred to our facility and underwent aortic valve replacement, 2- vessel coronary artery bypass grafting and intra-aortic balloon pump placement. Over the next 12 days he developed acute oliguric kidney injury requiring continuous renal replacement therapy. His course was further complicated by numerous episodes of cardiac arrest secondary to ventricular dysrhythmias requiring CPR, cardio-version and multiple antiarrhythmic agents. Despite maximal medical therapy, the ventricular dysrhythmias continued, resulting in profound hemodynamic instability and cardiogenic shock. He was percutaneously cannulated for veno-arterial extracorporeal membrane oxygenation (VA ECMO) on hospital day 12. He continued to have episodes of dysrhythmias that were refractory to antiarrhythmic agents. Despite maximal medical therapy, the ventricular dysrhythmias continued, resulting in profound hemodynamic instability and cardiogenic shock. He was transferred to the cardiovascular intensive care unit for balloon atrial septostomy on hospital day 21. Following this procedure his hemodynamics and dysrhythmias improved significantly allowing him to undergo more vigorous physical therapy for the first time during his hospitalization.

Over the next few weeks, he underwent aggressive physical reconditioning with the aid of physical therapist and nurses. By hospital day 28, he progressed to sitting on the edge of the bed with assistance. By hospital day 41, he advanced to standing with assistance for 2- minute intervals. By hospital day 55, he successfully ambulated 98 feet. Once the endocarditis was completely treated and he was ambulating daily, he was listed status 1A for combined heart and kidney transplantation with the United Network for Organ Sharing (UNOS).

While awaiting transplantation he continued to ambulate almost daily, limited at times by cannula site bleeding that required blood transfusions and suture reinforcement around the cannula sites. On hospital day 88, day 76 of VA ECMO, he successfully underwent heart and kidney transplantation and was decannulated from VA ECMO. On postoperative day (POD) 2, he was tolerating continuous tracheostomy collar and by POD 5, he was ambulating with physical therapy. On POD 10 (hospital day 98), he was transferred to the telemetry unit. He was briefly readmitted to the ICU after developing a pericardial effusion from a heart biopsy that required a pericardial window. On hospital day 111, he was discharged to an inpatient rehabilitation facility where he spent a total of 5 days before being discharged home.

At experienced institutions, VA ECMO can be used effectively for prolonged durations in order to optimize patients for potential candidacy for organ transplantation. Maximizing physical rehabilitation preoperatively can lead to shorter postoperative hospital and rehabilitation length of stay and can potentially improve outcomes.

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In-Vitro Comparison of Hemodynamic Performance of Three ECLS Systems in an Adult Cardiogenic Shock Model
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Objective: Currently, several devices are able to provide circulatory support for patients with cardiogenic shock. Translational research has helped to assess the components of ECLS circuitry. The objective of this study was to evaluate three commercially available ECLS systems with rotary pumps in terms of circuit pressure, pressure drop, and hemodynamic energy transmission in a simulated adult cardiogenic shock model. Total hemodynamic energy (THE) was used as an index of the energy carried by blood. Delivering more THE to patients helps to maintain better microcirculation and vital organ perfusion.

Methods: The experimental circuit consisted of two ECLS circuits set up in parallel. One circuit consisted of a Cardiohelp system, which included a Cardiohelp console and an HLS Module Advanced 7.0 with integrated centrifugal pump and oxygenator. Another circuit was composed of a Quadrox-D Adult oxygenator connected in series with an i-cor diagonal pump and console or a Rotaflow centrifugal pump and console. The circuit was primed with lactated Ringer’s solution and packed red blood cells (hematocrit 40%). Trials were conducted at flow rates of 1–5 L/min (1 L/min increments) with pseudo patient pressures of 60 mmHg and 80 mmHg. Pulsatile flow was tested when using the i-cor system. Real-time pressure and flow data were recorded for analysis.

Results: Mean pre-oxygenator pressure and pressure drop across the ECLS circuit (including oxygenator and arterial tubing) were lower when using the Cardiohelp system as compared to the Rotaflow and i-cor systems (pre-oxygenator pressure: Cardiohelp: 83.8–258.7 mmHg, Rotaflow: 87.1–268.4 mmHg, i-cor: 88.1–283.8 mmHg; circuit pressure drop: Cardiohelp: 23.3–178.8 mmHg, Rotaflow: 26.8–187.5 mmHg, i-cor: 27.4–204.3 mmHg). The i-cor system was able to deliver more hemodynamic energy to the pseudo patient because of its ability to produce pulsatile flow. The Cardiohelp HLS Module Advanced 7.0 integrated oxygenator had a lower resistance than the Quadrox-D oxygenator (pressure drop: 10.7–50.4 mmHg vs. 13.5–73.6 mmHg).

Conclusions: The three ECLS systems are suitable for circulatory support in adult patients with cardiogenic shock. Although the compact Cardiohelp system had a better hemodynamic performance when compared to Rotaflow and i-cor systems, the pulsatile flow of the i-cor system delivered more hemodynamic energy to the pseudo patient. This may render more benefits in high-risk patients on ECLS.

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Evaluation of Hemodynamic Performance of a Combined ECLS and CRRT Circuit in Seven Positions with a Simulated Neonatal Patient
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Objective: The objective of this study was to evaluate an alternative neonatal extracorporeal life support (ECLS) circuit containing either a Maquet RotaFlow centrifugal pump or Maquet HL20 roller pump with one of seven configurations of CRRT using the Prismaflex 2000 System.

Methods: All ECLS circuit setups included a Quadrox-d Pediatric diffusion membrane oxygenator, a Better Bladder, an 8-Fr arterial cannula, a 10-Fr venous cannula, and 6 feet of ¾-inch diameter arterial and venous tubing (Figure 1). The circuit was primed with lactated ringer’s solution and packed human red blood cells resulting in a total priming volume of 700 mL for both the circuit and the 3kg pseudopatient. Hemodynamic data was recorded for ECLS flow rates of 200, 400, and 600 mL/min and a CRRT flow rate of 50mL/min. Figure 2 presents seven CRRT positions within ECLS circuit.

Results: When a centrifugal pump is used, the hemodynamic performance of any combined ECLS and CRRT circuit was not significantly different than that of the circuit without CRRT, thus any configuration could potentially be used. However, introduction of CRRT to a circuit containing a roller pump does affect performance properties for some CRRT positions. The circuits with CRRT positions B and G demonstrated decreased total hemodynamic energy (THE) levels at post-arterial cannula site, while positions D and E demonstrated increased post-arterial cannula THE levels compared to the circuit without CRRT. CRRT positions A, C, and F did not have significant changes with respect to pre-arterial cannula flow and THE levels, compared to the circuit without CRRT.

Conclusions: Considering hemodynamic performance, for neonatal combined ECMO and CRRT circuits with both blood pumps, we recommend the use of CRRT position A due to its hemodynamic similarities to the ECMO circuit without CRRT.

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In-vitro Hemodynamic Evaluation of ECG-Synchronized Pulsatile Flow in a Simulated Adult ECLS System

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Objective: The novel i-cor ECLS system can generate pulsatile flow synchronized with a patient’s heartbeat. Currently, the impact of the i-cor system’s pulsatile settings on hemodynamic performance is unknown in adult patients. The objective of this study was to evaluate the i-cor electrocardiogram (ECG)-synchronized cardiac assist system in terms of hemodynamic energy generation and transmission under various pulsatile amplitudes, flow rates, and pseudo patient pressures in a simulated adult ECLS circuit. Surplus hemodynamic energy (SHE) is a measure of the quality of pulsatility, and higher SHE levels correlate with improved microcirculation and tissue perfusion.

Methods: The circuit consisted of an i-cor diagonal pump, an adult Xlung oxygenator, a 21 Fr Medtronic Biomedicus femoral arterial cannula, a 23/25 Fr Sorin RAP femoral venous cannula, and 3/8 in ID tubing for both arterial (5 feet) and venous lines (4 feet). The circuit was primed with lactated Ringer’s solution and then packed red blood cells (hematocrit 37%). Trials were conducted at 36°C with flow rates of 2–5 L/min (1 L/min increments) under non-pulsatile and pulsatile mode with pulsatile amplitudes of 1,000–5,000 rpm (1,000 rpm increments). The pseudo patient pressure was maintained at 40–100 mmHg (20 mmHg increments). Real-time pressure and flow data were recorded for analysis using a custom-made data acquisition system.

Results: There was no surplus hemodynamic energy (SHE) generated by the pump under non-pulsatile mode. Under pulsatile mode, SHE levels increased with increasing pulsatile amplitudes and pseudo patient pressures (p<0.01) but decreased with increasing flow rates (Figure 1). Total hemodynamic energy (THE) levels had the similar trend as SHE levels. In addition, the Xlung oxygenator had acceptable pressure drops (36.1–104.9 mmHg) and percentages of THE loss (19.6–43.9%) during all trials.

Conclusions: The i-cor ECG-synchronized cardiac assist system can provide not only non-pulsatile but also pulsatile flow in an adult ECLS circuit. However, pulsatility gradually weakened with increasing flow rates. Pulsatile amplitude settings were found to have a great impact on pulsatility.

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Retrospective review of hemolysis during pediatric extracorporeal membrane oxygenation with a centrifugal pump

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The use centrifugal pumps (CP) for ECMO has grown in popularity in the last 15 years with the advent of new technology. Advocate Children’s Hospital transitioned from roller pumps to CP in the last 10 years. Although the use of the CP has spread there has been literature to support the continued use of roller pumps due to increased hemolysis with the use of CP. Hemolysis is not uncommon during ECMO due to the artificial surface area and shear stresses forces on blood elements. Patients with hemolysis may have a longer ECMO run, require more blood products and those with severe hemolysis have increased risk of mortality. (1) The incidence of reported hemolysis with a centrifugal pump varies from 64% to 81% (1, 5).

O’Brien and associates performed a logistic regression based on data collected from the ELSO registry (2). They found significantly greater hemolysis with use of CP versus roller pump. But the overall rate of hemolysis was only 14% (2). Even with the use of newer generation CP, these patients continued to demonstrate increased hemolysis, hyperbilirubinemia and acute renal failure (3). Others have found opposite findings. Byrnes compared the use of a roller pump and CP at a single institution and demonstrated increased hemolysis with the roller pump (4).

Due to mixed literature attempting to distinguish which pump is ideal for ECMO, we are performing a retrospective study on our ECMO patients to review our incidence of hemolysis with the use of CP. According to Extracorporeal Life Support Organization (ELSO), hemolysis is defined as plasma-free hemoglobin (pfHgb) greater than 50 mg/dl. PfHgb levels along with other ECMO parameters were recorded to determine the degree of hemolysis. Jenks and associates found an Hgb level greater than 13 g/dl increased the incidence of hemolysis (5). If elevated pfHgb levels are routinely encountered on our ECMO patients a regressional analysis may bring to light some possible risk factors of hemolysis such as hgb levels, cannula size or amount of revolutions per minute (RPM) required to achieve adequate flow.


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Background: Extracorporeal cardiopulmonary resuscitation (ECPR) is increasingly used in critically ill children who suffer cardiac arrest without return of spontaneous circulation despite conventional CPR. High quality CPR as well as the time to attainment of ECMO flows are critical to the patient’s outcome. However, providing quality CPR during ECPR(ECMO) cannulation presents unique challenges in the pediatric patient. As part of a Pediatric Intensive Care Unit (PICU)-wide quality CPR and ECMO quality improvement project, we conducted serial ECPR simulations to assist in perfecting the multidisciplinary coordination of this low-frequency but potentially lifesaving enterprise. We analyzed quality CPR and ECPR activation/cannulation process metrics recorded during the ECPR simulations, with the goal of determining which such process metrics need improvement that could ultimately lead to better patient outcomes.

Methods: Two independent medically trained reviewers extracted data from s-series Zoll defibrillators and from video recordings of multidisciplinary in situ ECPR simulations conducted between 2015 to 2017 in an academic, quaternary care PICU. The simulation involved an infant with cardiac arrest secondary to ventricular fibrillation. We extracted critical data points for pre-determined process metrics: time from onset of arrest to: chest compressions (target <10 sec), activation of ECMO team (target 5 min), time on ECMO (target <30 min), first defibrillation (target <180 sec), and first epinephrine administration (target <5 min); pauses in CPR during cannulation; and quality of CPR (depth and rate of chest compressions, total compression fraction). Process metrics were derived from published AHA PALS guidelines and ECMO outcomes literature.

Results: We reviewed 12 ECPR simulations. The median time from onset of cardiac arrest to ECMO activation was 3.4 min (IQR 2.1–4.2) and the median time to obtaining ECMO flow was 32.4 min (IQR 30.3–38.4). The median time from onset of arrest to CPR initiation was 10 sec (IQR 8–10), median time to first epinephrine administration was 3.25 min (IQR 2.5–4.2) and median time to first defibrillation was 269 sec (IQR 196–315). The percentage of total CPR time that was within the goal compression rate was 30.8% (IQR 12.3–54.5%) and the median compression fraction was 87% (IQR 82–89%). The median number of pauses in CPR lasting >10 sec was 6.8 (IQR 6.5–8.3) and the median longest pause was 34.2 seconds (IQR 27.9–35.8).

Conclusion: In this single center QI project of ECPR simulation using a high fidelity mannequin and Zoll defibrillator for CPR feedback, we identified numerous areas that need improvement through targeted training. Specifically, we performed within pre-established goals for time to initiation of CPR, first epinephrine administration and activation of the ECMO team. However, a systematic review of processes and further team training will be done in order to improve the time to first defibrillation, total compression fraction, rate of chest compressions, time to obtaining ECMO flows as well as aim to minimize pauses lasting greater than 10 seconds.

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Retrospective Outcomes Analysis of ECMO Patients Anticoagulated with Heparin vs. Bivalirudin

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Introduction: Unfractionated heparin (UFH) is the most common anticoagulant used in ECMO patients. It is often considered as the anticoagulant of choice due to the abundant clinical experience, low cost, and available reversal agent. There is increasing awareness of the clinical constraints of heparin, including heparin-induced thrombocytopenia (HIT, HITT), heparin resistance, and blood product transfusion. The anticoagulant bivalirudin, a direct thrombin inhibitor, is potentially an ideal anticoagulant for ECMO with its short half-life, absence of resistance, and no associated thrombo-cytopenia. In 2013, bivalirudin replaced UFH as the main anticoagulant for patients on ECMO at IUH Methodist Hospital. We compare the outcomes of ECMO patients anticoagulated with UFH vs bivalirudin.

Methods: A retrospective, single center review was performed on patients receiving ECMO support who were anticoagulated with either UFH or bivalirudin for greater than 24 hours from January 2010 to May 2016. Data collected includes age, gender, type of ECMO circuit, time on ECMO and indication for ECMO. The quantity and type of blood products transfused while on ECMO support was analyzed. Outcomes including survival off ECMO, survival to discharge, and incidence/location of symptomatic deep vein thrombosis were also quantified. A univariate statistical analysis was performed for both UFH and bivalirudin to compare outcome variables.

Results: The study included a total of 176 patients: 132 received bivalirudin and 44 received heparin. Baseline demographics were similar between the UFH and bivalirudin groups including age, gender, and type of ECMO support. Mean length of ECMO support for bivalirudin patients was 196 hours versus heparin patients 78 hours. Patients anticoagulated with bivalirudin had an in-range therapeutic aPTT of 73.6% while patients on heparin had in-range therapeutic aPTT of 14.6% (p <.001). Survival to decannulation was 74% in bivalirudin patients versus 78% in heparin patients. Of the patients who survived decannulation, 80% of bivalirudin patients survived to discharge versus 96% of heparin patients. receiving bivalirudin survived to decannulation, of these patients, 80% survived to discharge, yielding an overall survival rate of 59%. 78% of heparin patients survived to decannulation, and of these, 96% survived to discharge.

Conclusions: At present, there is a paucity of literature comparing UFH and bivalirudin in ECMO patients. One key finding is that bivalirudin provided a more consistent, in-range therapeutic anticoagulation versus UFH. Our bivalirudin patients were supported on ECMO for a significantly longer period of time, more than doubling the support time for heparin patients. The longer duration of support, the variability of mode of ECMO support (VV vs VA), and the programmatic learning curve in ECMO management may contribute to the survival differential between the two agents of anticoagulation.

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Outcomes of Central vs. Peripheral Veno-Arterial ECMO Cannulation: A Single Center Experience

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Background: Veno-arterial ECMO (VA ECMO) is an effective technique that has been used to provide mechanical circulatory support for refractory cardiogenic shock. It can be initiated in various configurations – primarily distinguished between peripheral cannulation via the femoral vessels and central cannulation in the chest. We analyzed the outcome differences between these two cannulation approaches.

Methods: This is a single center retrospective analysis of VA ECMO patients from March 2012 to April 2017. A total of 130 patients are included: 86 patients received central cannulation and 44 patients received peripheral cannulation. These patients included patients cannulated at our hospital and those cannulated at other hospitals and transferred to definitive management. We compared the demographics of the two groups and examined various independent variables. Outcomes of survival off ECMO, survival to discharge, and complications were examined. Central cannulation technique utilized right atrial – ascending aorta. Peripheral cannulation was via femoral vessels with distal perfusion catheter being placed by interventional radiology following the initial cannulation. Anticoagulation was with heparin and bivalirudin.

Results: The mean age of the 130 patients was 53 years with a male predominance distribution of 67%. The majority of indication for VA ECMO support was post-cardiomyopathy shock (52.3%) and acute myocardial infarction (9.2%). Of note, eCPR represented 5.4% of the patients. Overall survival off VA ECMO in this group was 50% and survival to discharge was 34.6%. The survival off ECMO for centrally cannulated patients (51.2%) and peripherally cannulated patients (47.7%) was not significantly different (p = .85). For survival to discharge, the higher survival in central cannulation patients (40.7%) versus peripheral cannulation patients (22.7%) approached statistical significance (p = .052). In patients who survived off ECMO support, venous thromboembolic (VTE) complications was not statistically significant different between central (25%) versus peripheral cannulation (14.3%, p = 0.34). We did not identify any independent predictors of VTE in either group of VA ECMO patients.

Conclusion: Our results suggest survival off VA ECMO support is not different between central versus peripheral cannulation approach. The survival difference to discharge likely reflects the longer term complications of the different patient groups, such as eCPR. With the use of fluoroscopically guided placement of distal perfusion catheters, there has not been ischemic limb complications with peripheral cannulation. VTE prevalence was not statistically different between the two groups, although the overall occurrence is noteworthy. We did not identify studied variables that were associated with VTE, including the use of heparin and bivalirudin.

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Case Report: Successful Recovery from Polysubstance Overdose Induced Circulatory Collapse with Venous-Arterial ECMO Support Initiated in ED

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Introduction: Substance and polysubstance abuse is an increasing socioeconomic problem often requiring advance resuscitation techniques to successfully treat the cardiopulmonary failure that may ensue. We describe a recent case of a 30 year old female admitted to the Emergency Department for polypharmacy ingestion and resulting circulatory failure.

Presentation: 30 year-old white female with significant past psychiatric (bipolar disorder, anxiety, intermittent explosive disorder, substance abuse, prior suicide attempts) and medical history (hepatitis C, hypertension, GERD, Arnold-Chiari malformation) was admitted to the Emergency Department. Emergency medical services (EMS) were notified due drug overdose. She was initially awake and ambulatory when EMC arrived. Empty bottles of propranolol, amitriptyline, lamictal, prazosin, and quetiapine were found at the scene. EMS was informed that beer was ingested along with the medications. During transport to the hospital, she became hypotensive and obtunded.

ED Course: Upon arrival to the Emergency Department (ED), her GCS was 3 with systolic blood pressure of 60. She was immediately intubated. Her EKG demonstrated rate 59, QRS 108msec, P-R interval 172msec, and QTc 486msec. Central access was obtained. She was resuscitated with rounds of glucagon, insulin, glucose boluses. She was then started on continuous bicarbonate, insulin, glucagon, norepinephrine and epinephrine infusion. She remained profoundly hypotensive, systolic blood pressures in the 60s. She then developed first degree AV block.

The ECMO team was consulted and the patient rapidly assessed in the ED. Plan was to provide VA ECMO support until the pharmacologic effects of the drug ingestion resolves. She was underwent emergent percutaneous peripheral cannulation: 18Fr arterial cannula in left femoral artery and 24Fr venous cannula in left femoral vein. Her blood pressure rapidly improved to systolics of 120s. She was transferred from ED to the interventional radiology suite, where a 5Fr distal perfusion catheter was placed into the left superficial femoral artery from the right common femoral artery under fluoroscopy.

Hospital Course: Patient was able to be rapidly weaned off her pressor support. Norepinephrine was titrated off 4 hours following the initiation of ECMO support. Epinephrine was discontinued after 3 days of support. She continued to improve. On ECMO support day 6, she was taken to the operating room and underwent decannulation and repair of her femoral vessels. She was extubated in the immediate post-operative period. She was then transferred to inpatient psychiatric service for further treatment. She was successfully discharged home on hospital day 32 without any residual medical sequelae.

Summary: VA ECMO can successfully support cardiovascular collapse due to polysubstance ingestion.

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It takes a Village to provide Advanced Physical Therapy: The Value of a Collaborative Early Mobility Program to restore Function for Patients on Extra Corporeal Membrane Oxygenation (ECMO) support.

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Early mobility has become recognized as an important component in the management of critically ill patients. The Awakening and Breathing, Coordination, Delirium Monitoring and Management, Early Mobility and Family Engagement (ABCD) Bundle is an evidence based nursing model that promotes interdisciplinary collaboration with the goal to reduce iatrogenic effects. Despite the encouraged collaboration, patient care frequently occurs in disciplinary silos that can reduce the quality of care especially for the medically complex like patients on Extracorporal membrane oxygenation (ECMO) support. The physical therapists at the University of Maryland Medical Center (UMMC) are using the nursing based early mobility program as a means to provide advanced rehabilitation services to patients on ECMO support. The early mobility program includes a mobility leveling component that describes the functional status of the patient on a scale of 1 (dependent functional level) to 5 (independence). Physical therapists have implemented a screening process that assesses the readiness and appropriateness to mobilize patients on ECMO, including those with femoral cannulation sites. By using the mobility Level, screening tool, and the physical therapy (PT) assessment the physical therapist can not only deliver safe functional mobility training, but can make specific activity recommendations to the bedside nurse, patient and family members. This process promotes a focused exercise program that extends beyond the PT session and further contributes to the restoration of functional activities that are being addressed with the physical therapist. This approach has allowed the physical therapist to perform such advanced activities as high-level balance activities, muscle endurance training, and manual therapy to restore joint function and normalize gait patterns. The purpose of this proposal is to describe the integrative and multidisciplinary approach that is being used at UMMC to provide advanced rehabilitation services to ECMO supported patients including those with femoral cannulation sites

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Providing Early Rehabilitation and Ambulation to Adults on Percutaneous Venous to Arterial Extracorporeal Membrane Oxygenation Support

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Introduction / Rationale: At the University of Maryland Medical Center there has been an increase utilization of Venous to Arterial Extracorporeal Membrane Oxygenation (VA ECMO) to support adults who suffer acute refractory cardiogenic shock. Early rehabilitation including ambulation for ECMO-supported patients began in 2009 at UMMC, and has evolved to become the standard of care when medically appropriate despite the cannula site. A physical therapy screening tool and advanced training along with a collaborative multidisciplinary team, has allowed for successful rehabilitation of patients on VA ECMO even those patients with femoral cannulation. The purpose of this retrospective observational study was to examine the feasibility and safety of mobilizing patients on VA ECMO.

Methods: After obtaining IRB approval, data mining of UMMC electronic medical record (EMR) system was completed for all adult patients on VA ECMO from January 2014 to December 2015 and we continue to comply with the data for 2016. Variables included: demographics; ECMO-related data; frequency and type of mobility completed; highest level of functional mobility achieved while on VA ECMO support; and outcomes. The EMR and incident reports were reviewed for any adverse events related to physical therapy.

Results: Between January 2014 and December 2016 there were 171 adult patients supported on VA ECMO. Sixty percent of this group were male with a mean age of 53.1 years ± 3.53. The predominate medical diagnoses were cardiogenic shock, pump dysfunction post open heart procedures, and pulmonary embolus. Sixty-eight patients were supported on percutaneous femoral cannulation site(s) and 17 patients were centrally cannulated. Physical Therapy was consulted on 79% of the patients and a total of 286 therapy sessions were provided; 229 mobility activities were completed during ECMO support including 138 sessions of functional mobility, and 73 sessions involving standing activities and ambulation. Eight patients progressed to ambulation with distances ranging from 30 to 600 feet while on VA ECMO. Finally, the data from 2014 to 2015, 58% of the patients were successfully weaned from ECMO and discharged, 54% achieved an ambulatory status prior to discharge either home or to a rehabilitation facility. The preliminary results from 2016 has shown that 21% of these patients were discharge home. Currently the team is completing the data mining and analysis for the rest of the 2016 cohort. There were no major or minor adverse events reported related to early rehabilitation with ambulation

Conclusion: This retrospective study demonstrated with proper advanced training, a multidisciplinary team approach, and an effective screening process, early rehabilitation is not only feasible but is safe to perform with patients on VA ECMO. Future work should examine the effects of rehabilitation on long term functional outcomes, including the management of post intensive care syndrome.

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PEDIATRIC ECMO MOBILITY REQUIRES AN INTERDISCIPLINARY CULTURE SHIFT
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Introduction: Utilizing ECMO for a bridge to lung transplantation in Pediatrics involves optimal trust, collaboration, managed risk-taking and teamwork of multiple disciplines. The goal of ECMO mobilization for pediatric patients awaiting lung transplantation is to preserve muscle tone by actively participating in therapy, to in theory, improve lung transplant outcomes. Team lessons learned from a case of pediatric ECMO will be presented.

Methods: The goal to develop a plan for ECMO Mobility began at our institution in 2014. A retrospective review of the T. M. case (April 2017 through June 2017) taught the ECMO Center Team a multitude of lessons. Awake and responsive children and teenagers requires heavy involvement and collaboration with Physical Therapy (PT). Occupational Therapy (OT) and Child Life Specialists when the patient is deemed stable enough to lighten sedation to increase patient involvement and movement. Progressive ECMO mobility began on day one of VVDL ECMO via RIJV for T.M., a trached 12 year old female with Cystic Fibrosis requiring a lung transplant. A specific, measurable progressive assessment and plan for attainable daily goals began with tolerating sitting and assisted moving from bed to chair. The plan progressed from standing, treadmill walking using a harness for support, to walking the hallway with safety measures incorporated for potential needs for a break/rest within the first 48–72 hours of ECMO initiation.

Results/Conclusion: Reconditioning the muscles of a child on ECMO is a staged process. Collaboration among the family and patient and health care team includes a multitude of alternative disciplines available to consult and customize the patient and family ECLS experience. Overcoming personal bias and fear related to fatal harm due to accidental decannulation was addressed daily on bedside rounds by the entire healthcare team.

Progressive ECMO mobility can be a safe expected regimen for compliant patient populations.

A Retrospective Analysis of the Outcomes of Extracorporeal Cardiopulmonary Resuscitation (ECPR)
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Objectives: This was a retrospective study on the overall disposition at discharge of patients undergoing extracorporeal cardiopulmonary resuscitation (ECPR) at a single institution from 2013–2017. ECPR is a form of veno-arterial extracorporeal membrane oxygenation (VA-ECMO) administered while a patient is undergoing cardiac arrest without the return of spontaneous circulation (ROSC). The aim of this study was to perform an analysis on the outcomes of ECPR to determine its overall effectiveness and potential to improve short-term outcomes of cardiac arrest patients.

Methods: The analysis was conducted on all patients who underwent ECPR between 2013 and 2017 at a single institution, which included 45 total patient with a mean age of 54.2 ± 17.3 years [14,78] and a gender distribution of 35 (78%) males to 10 (22%) females. Demographic information, related variables, and outcomes were recorded.

Results: The findings of this analysis showed that of the 45 patients who underwent ECPR, 29% (95%CI 16–42%) had an outcome of survival at discharge. This study demonstrated a 14% increase in survival at discharge between two time periods (Cohort 1: 2013–2015, Cohort 2: 2016–2017). In addition, all patients had been weaned from ECPR or had care withdrawn by or on day 8 with an exception of 2 patients who were weaned on day 24 and 26, though both were converted to veno-venous extracorporeal membrane oxygenation (VV-ECMO) on day 8 and 2, respectively.

Conclusions: Survival of cardiac arrest patients without ROSC is very poor without any adjunctive treatment. Patients who underwent ECPR had a survival to discharge rate of 29%. Survival improved with increased experience of the team and institution over time.

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ELSO Author Index

Abdel-Rasoul, Mahmoud ................................................. 43
Abdulhai, Sophia ................................................................. 19
Abu-Hijleh, Muhammed ................................................. 14
Aki, Ali ....................................................................... 1
Alaish, Samuel ................................................................. 19
Alexander, P ................................................................. 37
Amin, Ruchi .................................................................. 1
Anderson, E .................................................................... 49
Anderson, Eve ................................................................ 50
Antes, T ......................................................................... 2
Antes, Traci ..................................................................... 49
Aokage, Toshiyuki ............................................................ 2
Arbabi, Saman ................................................................ 21
Askenazi, David .............................................................. 32
Austin, Audrey ............................................................... 11
Bacigalupo, Carl H .......................................................... 14
Badjatia, Neeraj .............................................................. 28
Bahamondes, Rodrigo ..................................................... 27
Bailly, David .................................................................... 45
Bailly, David K . .............................................................. 6
Bain, Jennifer M. ............................................................ 1
Balch, Alfred .................................................................... 45
Barber, Jimmy ................................................................. 11
Bastero, Patricia .............................................................. 38
Battarjee, Wejdan ............................................................ 5
Beaty, Chris .................................................................... 41
Beaty, Christopher .......................................................... 18
Becker, Pedro ................................................................... 27
Bembea, Melania ............................................................ 19
Bembea, Melania M ......................................................... 5, 49
Bembea, M.M ................................................................. 2
Benhararsh, Peyman ....................................................... 20
Berry, N ........................................................................ 49
Berry, Natalie ................................................................. 50
Bertrand, Pablo ............................................................... 27
Bhat, Aarti H ................................................................... 3
Bhatia, P .......................................................................... 2
Bhatia, Jatinder ............................................................... 41
Bianchi, Joseph ............................................................. 11
Blough, Britton A ........................................................... 4
Boehme, Amelie ............................................................. 1
Bonadonna, Desiree ........................................................ 4, 5
Boyle, Katharine E ......................................................... 5
Brehm, Christoph E ........................................................ 38, 39, 47, 48
Bridges, Brian C ............................................................ 26, 32
Brindle, Mary E ............................................................. 22
Brodecki, Darcy ............................................................. 17
Brogan, Thomas ........................................................... 10
Brogan, Thomas V .......................................................... 3
Brunetti, Marissa A ........................................................ 6
Buckley, JR .................................................................... 8
Buckley, MJ .................................................................... 8
Buckvold, Shannon ........................................................ 42
Budzynski, Katrina ........................................................ 52
Bulger, Eileen ............................................................... 21
Burke, Chris ................................................................... 10
Burke, James ................................................................... 52
Burkhardt, Meghan ....................................................... 52
Burkhardt, Harold M ....................................................... 25
Burns, Deborah ............................................................. 46
Cahill, Erin ..................................................................... 1
Calame, Colette ............................................................. 25
Caldwell, Domenico ........................................................ 6, 7
Capes, JL ........................................................................ 8
Cardona, Matthew ........................................................ 8
Cardona, MF .................................................................... 8
Carella, Dominick M ....................................................... 9
Carr, Ben ...................................................................... 45
Castillo, Andrés ............................................................ 27
Castle, Shannon ............................................................. 26
Catron, Leslie ............................................................... 31
Caywood, Emi ............................................................... 18
Chae, Floreira E ............................................................ 9
Chandler, Wayne L ......................................................... 10
Cheung, Eva ................................................................... 1
Chung, Dai H ................................................................. 26
Colombo, Paolo C .......................................................... 30
Connelly, Jim ................................................................ 52
Conrad, Steven A ........................................................ 11, 29
Cooper, David ............................................................... 32
Córdova, Guiliana .......................................................... 27
Costello, William ......................................................... 23
Craig, Lynne ................................................................. 11
Cristian, Fajardo ........................................................... 33
Cropsey, Christopher .................................................... 11, 23
Cua, Clifford L ............................................................. 14
Cudemus, Gaston .......................................................... 15
Cuschierei, Joseph ........................................................ 21
D’Alessandro, David A ................................................... 15
Dalia, Adam ................................................................... 15
Dalton, Heidi ............................................................... 12
Daneshmand, Mani ........................................................ 5
Daniela, Martinez ......................................................... 33
Danielle, Ransonette ..................................................... 24
Danko, Melissa E ............................................................ 26
Dashetwar, Abhiheeth .................................................... 37
Davis, JD ....................................................................... 22
Davis, Joel .................................................................... 44
Davis, Susan L ............................................................. 6
Dawoud, Fakhry ............................................................ 26
De La Cruz, Kim ........................................................... 20
del Pozo, Paulina .......................................................... 27
Desai, Mehul ................................................................. 12
Devor, Renee ............................................................... 13
Dewire, Jane ................................................................... 43
Dhanani, Hussain ........................................................ 12
Diaz, Ann ..................................................................... 13
Diaz, Sebastian ............................................................. 4
DiNardo, JA ................................................................. 37
DiNardo, P .................................................................... 37
Dinnelberger, Daniel ..................................................... 18, 41
dos Reis Miranda, D ....................................................... 33
Dodge, P ....................................................................... 2
Dodson, A ..................................................................... 2
Douglé, Ghislaine .......................................................... 40
Duffy, Vicky ................................................................... 14
Dubois, H ..................................................................... 14
Duval-Arnold, J .............................................................. 49
Eaton, Jonathan ............................................................. 29
El Banayosy, Aly ............................................................ 21
Elizabeth, Schroeder ..................................................... 24
Ely, Elizabeth ............................................................... 17
Emami, R ...................................................................... 37
Emami, S ...................................................................... 37
Emerson, Logan J .......................................................... 2
Engelhardt, Kevin ......................................................... 14
Esbensen, J .................................................................... 2
Estay, Alberto ............................................................... 27
Ester Pizarro, Maria ....................................................... 27
Eugenia Pérez, Maria .................................................... 27
Fabres, Jorge ................................................................... 27
Fallon, Brian .................................................................... 1

53
<table>
<thead>
<tr>
<th>ELSO Author Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan, Eddy</td>
</tr>
<tr>
<td>Farneman, Michelle</td>
</tr>
<tr>
<td>Faunes, Miriam</td>
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<tr>
<td>Faylor, Connie</td>
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<td>Felipe, Salech</td>
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<td>Felling, Ryan</td>
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<td>Felt, Jason</td>
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<td>Fiedler, Amy G.</td>
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<td>Fischer, Stefan</td>
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<td>Fleming, Geoffrey</td>
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<td>Floyd, S</td>
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<td>Force, Madison</td>
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<td>Ford, K</td>
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<td>Ford, Ken</td>
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<td>Foreman, Celeste</td>
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<td>Forrester, Jenny</td>
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<td>Francisovich, Christine D.</td>
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<td>Frazier, B.</td>
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<td>Freeman, Lloyd</td>
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<td>Frizolli, Meg</td>
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<tr>
<td>Froehlich, Curt</td>
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<tr>
<td>Fukushima, Naoya</td>
</tr>
<tr>
<td>Gaber, Michael</td>
</tr>
<tr>
<td>Gadepalli, Samir K</td>
</tr>
<tr>
<td>Gaies, Michael</td>
</tr>
<tr>
<td>Gallagher, Kennedy</td>
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<tr>
<td>Galvagno, S</td>
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<tr>
<td>Garan, A. Reshad</td>
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<td>Garcia, A</td>
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<td>Garcia, Alejandro</td>
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<td>Garcia, Alejandro V.</td>
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<td>Gaynor, J. William</td>
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<td>Geller, Emily G.</td>
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<tr>
<td>Gibbs, AD</td>
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<tr>
<td>Gibbs, JL</td>
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<td>Glenn, Ian C.</td>
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<td>Godoy, César</td>
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<td>Gomez, Avraham</td>
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<td>Gomez, Daniel</td>
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<td>Gomers, D.</td>
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<td>González, Alvaro</td>
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<td>González, Rodrigo</td>
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<td>Gray, A</td>
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<td>Green, Rebecca</td>
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<tr>
<td>Griffith, Elaine</td>
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<tr>
<td>Guadueno, Vadim</td>
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<tr>
<td>Guerrierian, Anne-Marie</td>
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<tr>
<td>Guerrero, Ximena</td>
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<tr>
<td>Guillermo, Herrera</td>
</tr>
<tr>
<td>Gunville, Cameron</td>
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<tr>
<td>Gutteridge, D</td>
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<tr>
<td>Hage, C</td>
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<tr>
<td>Hamilton, Jessica</td>
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<tr>
<td>Hammond, Matt</td>
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<td>Harper, Michael D.</td>
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<td>Harting, Matthew T.</td>
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<td>Hatley, Robyn</td>
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<tr>
<td>Heard, Micheal</td>
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<td>Heard, ML</td>
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<tr>
<td>Heather, Beth</td>
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<tr>
<td>Hebbar, K</td>
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<td>Hebert, Daniel</td>
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<tr>
<td>Henson, C. Patrick</td>
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<td>Herrman, Stig Eggren</td>
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<td>Hernandez, Deborah A.</td>
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<td>Herr, Daniel</td>
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<td>Heyrend, Carly</td>
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<td>Name</td>
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<tr>
<td>Luco, Matias</td>
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<td>Luk, Adriana</td>
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<tr>
<td>Luo, Shuhua</td>
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<tr>
<td>Lyden, Liz</td>
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<tr>
<td>Mallory, Palen</td>
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<td>Malone, Laura</td>
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<td>Mandell, Sam</td>
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<td>Mandigers, L.</td>
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<td>Mann, Blake</td>
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<td>Marini, Juan C.</td>
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<td>Martin, Abigail</td>
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<td>Martinez, Claudia</td>
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<tr>
<td>Masoli, Daniela</td>
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<tr>
<td>Mathew, Smitha</td>
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<td>Mazor, Robert</td>
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<td>Mazzetti, Michael</td>
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<td>McCarthy, Paul</td>
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<td>McDonough, Tiffany</td>
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<td>Miura, Masaru</td>
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<td>Moes, McCaela</td>
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<td>Moore, Jacob</td>
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<td>Moore, Rosario</td>
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<td>Naseh, Torvind</td>
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<td>Nandwani, Veena</td>
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<td>Sandhu, Hitesh S</td>
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<td>Sano, Miko</td>
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<td>Santelices, Felipe</td>
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<td>Sasaki, Ken</td>
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<td>Satyapriya, S. Veena</td>
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<td>Schad, Christine</td>
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<td>Schlager, Avraham</td>
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<td>Schwartz, Jamie McElrath</td>
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<td>Scott, Ian</td>
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<td>Scott, Kimberley</td>
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<td>Scott, L. Keith</td>
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<td>Seibert, Kelly</td>
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<td>Seigel, Shanna</td>
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<tr>
<td>Selevski, David</td>
</tr>
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<td>Sepulveda, Verónica</td>
</tr>
</tbody>
</table>
ELS0 Author Index

Service, Becky .......................................................... 44
Shank, Kaitlyn .......................................................... 47
Shekerdemian, Lara S. ............................................ 38
Shemir, Richard ..................................................... 20
Sheu, Christian ....................................................... 27
Shimizu, Naoki ....................................................... 2
Shoya, Kazuhiro ..................................................... 2
Siddique, Aleem ...................................................... 35
Siebenaler, Teka .................................................... 44
Singh, Ramesh ...................................................... 12
Singi, Salish .......................................................... 37
Smith, Pamela ........................................................ 48
Smith, T ................................................................. 50
Smith, Trey ........................................................... 45
Smith, Teka ............................................................ 2
Soto Aguero, Maria Jose ......................................... 32
Sueishi, Takayuki ................................................... 2
Suzuki, Kei ............................................................ 25
Sweerus, Kelly ....................................................... 15
Takayama, Hiroo .................................................... 30
Takeda, Koji .......................................................... 30
Tammy, Elizondo ................................................... 24
Taniguchi, Masashi ................................................ 2
Taylor, Mark .......................................................... 21
Terry, C ................................................................. 49
Thiagarajan, R ....................................................... 37
Thomas, Sunu ........................................................ 15
Thomas, Tina T ...................................................... 45
Thompson Maj, K. Brian ......................................... 26
Thompson, Jess L .................................................. 25
Timmapuri, Shaheen ............................................... 9
Tobin, Nicole ....................................................... 46, 51
Toso, Alberto ........................................................ 27
Toso, Paulina ........................................................ 27
Tripathi, Ravi ........................................................ 43
Tukacs, Monika ..................................................... 46
Tzanos, Deanna Todd ............................................. 44
Um, John .............................................................. 35
Undar, Akif ........................................................... 16
Undar, Akif ........................................................... 36, 47, 48
Upadhyay, Kirtkumar ............................................. 42
UBras, Cynthia ...................................................... 48
Urzú, Soledad ........................................................ 27
Valle, Patricio ........................................................ 27
Van Bergen, Andrew ............................................. 48
VanDinh, Travis .................................................... 18
Vicenio, Jacqueline ............................................... 52
Villavicencio, Mauricio ......................................... 15
Vogel, Josh ........................................................... 51
Wagoner, Scott .................................................... 44
Wagoner, SF ........................................................ 22
Walker, T .............................................................. 2
Walker, Tracie ...................................................... 49
Wang, I ................................................................. 49, 50
Wang, I-wen ........................................................ 50
Watson, Diamond ................................................ 51
Webber, Tony ........................................................ 2
Weems, Mark F .................................................... 42
Weingarten, Jordan S ............................................ 18
Welch, Erika ........................................................ 51
Wells, Chris ........................................................ 46
Wells, Chris L ....................................................... 51
Whelchel, Mark B ............................................... 38
White, Heidi ........................................................ 40
Whitson, Bryan .................................................... 43
Wilkinson, M ....................................................... 2
Williams, Susan B ................................................ 52
Wills, Rachel ........................................................ 52
Wise, Linda ........................................................... 41
Wotan, Karl .......................................................... 16, 47
Woitas, Karl ........................................................ 16
Wozniak, M .......................................................... 50
Wozniak, Thomas ................................................. 50
Wu, James ........................................................... 52
Yam, Nicholson .................................................... 10
Yamamoto, Yusuke .............................................. 2
Yiu, Alvin ............................................................. 5
Yoshimura, Yukihiro ............................................. 2
Young, J ................................................................ 22
Young, John ....................................................... 49
Yuki, K ................................................................. 37
Yukimitsu, Masahiro ............................................. 25
Zappitelli, Michael .............................................. 32
Zavala, Alejandro ............................................... 27
Zebuh, Carleen .................................................... 42
Zorn, Elizabeth .................................................... 13