Interhospital Aircraft/Ground Extracorporeal Membrane Oxygenation Transportation by a Mobile Extracorporeal Membrane Oxygenation Team: First Turkish Pediatric Case Series

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ABSTRACT

Objective: Extracorporeal membrane oxygenation is a life-saving treatment for patients with circulatory and respiratory failure refractory to standard therapy. However, safe and timely patient transport to the referral extracorporeal membrane oxygenation center is critical for better patient outcomes in patients with acute cardiogenic shock. This study aimed to describe children’s features who were transferred to our center under extracorporeal membrane oxygenation by aircraft/ground vehicle and demonstrated the importance of extracorporeal cardiopulmonary resuscitation for transported children.

Materials and Methods: We report the first Turkish pediatric case series of patients with acute cardiogenic shock transported by aircraft and ground ambulances on extracorporeal membrane oxygenation support to a referral extracorporeal membrane oxygenation center between January 2016 and January 2021.

Results: Overall, 6 patients on venoarterial extracorporeal membrane oxygenation support were transported by aircraft and ground vehicles to our pediatric intensive care unit. Transport was achieved by fixed-wing aircraft in 5 patients and commercial aircraft in 1. Our mobile extracorporeal membrane oxygenation team cannulated 3 patients, and 3 patients were cannulated by the team at the hospital they applied to. The median age was 112 (range: 14–204) months and the median weight was 28.6 kg (range: 8.6–57.2 kg). The etiology of acute cardiogenic shock was fulminant myocarditis in 4 patients, dilated cardiomyopathy in 1, and transposition of great arteries and atrial flutter in 1. The median distance of travel for the patients to our hospital was 618 (407–955) km. No adverse events were detected during aircraft or ground vehicle transport.

Conclusion: Mobile pediatric extracorporeal membrane oxygenation transport teams may provide safe aircraft and ground vehicle transportation in high-risk patients with acute cardiogenic shock bridging to survival or long-term circulatory support.

Keywords: Children, extracorporeal membrane oxygenation, pediatric intensive care, transportation

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is a life-saving therapy for patients with circulatory and respiratory failure aiming to bridge long-term solutions. Most information on ECMO use comes from the Extracorporeal Life Support Organization (ELSO) international registry. According to the last ELSO ECLS international summary report, in July 2020, more
than 10,500 patients with respiratory failure received ECMO support, and more than 12,800 patients with cardiac failure received ECMO. Extracorporeal membrane oxygenation is used to support extracorporeal cardiopulmonary resuscitation (ECPR) in nearly 5,086 pediatric patients as reported in the ELSO ECLS international summary report until 2020. Patients who need ECMO must be transported to a suitable medical facility if the patient in a center lacks ECMO service. The annual ECMO success of an ECMO center is proportional to the number of ECMO performed per year. It is risky to transport critically ill patients who need ECMO because they are usually hemodynamically unstable. Extracorporeal membrane oxygenation transfer was made in Western countries for many years on roads, helicopters, and aircraft. Few centers can perform ECMO transfers. There are specialized centers for cannulating the patient at the referring hospital and transporting them back to their hospital. Few centers are providing ECMO for pediatric patients in our country. Children are transferred to ECMO centers with traditional transport, and then, ECMO is often set up at receiving centers in our country. Extracorporeal cardiopulmonary resuscitation is a rescue procedure in which ECMO is urgently initiated in patients who have had a cardiac arrest (CA) and have failed conventional cardiopulmonary resuscitation (CCPR). As a result, the awareness and use of ECPR are increasing all over the world.

This study aimed to describe the clinical characteristics, management, and outcomes of venoarterial (VA) ECMO patients transported by aircraft and ground ambulance to a high-volume Turkish pediatric intensive care unit (PICU).

MATERIALS AND METHODS

In this report, patients who underwent VA-ECMO and were transferred to our PICU by aircraft from 2016 to 2020 were evaluated retrospectively. Patient age, weight, body surface area (BSA), diagnosis, ECMO indication, ECMO course, hospital course, mode and reason of transport, complications on transport, and outcomes were analyzed. The local Institutional Ethics Committee approved this study [sign number is 105-235-22]. Written informed consent was obtained from all patients’ relatives or their representatives, where necessary, from their legal authority. Our research was conducted according to the ethical principles of the World Medical Association Declaration of Helsinki.

Mobile Extracorporeal Membrane Oxygenation Team

Our pediatric mobile ECMO team consisted of a cannulating cardiovascular surgeon, a surgical fellow, an ECMO physician or pediatric intensivist, a perfusionist, and an ECMO scrub nurse.

Initiation of Venoarterial Extracorporeal Membrane Oxygenation

Venoarterial extracorporeal membrane oxygenation was established by the referring hospital personnel (3 patients) or by our mobile ECMO team (3 patients).

Extracorporeal Membrane Oxygenation Circuit

Extracorporeal Membrane Oxygenation circuit used in this study was a continuous flow centrifugal pump (JostraRotaflow®; Maquet Cardiopulmonary, Rastatt, Germany or Stockert Instrumente GmbH, Munchen, Germany), with a hollow fiber oxygenator (JostraQuadrox; Maquet Cardiopulmonary, Rastatt, Germany) or a polymethylpentene membrane (Dideco, Sorin Group, Mirandola, Italy).

Aircraft/Ground Ambulance Transport

In this case series, 5 patients were transported by fixed-wing aircrafts which were provided by the Turkish Ministry of Health (Cessna CJ2, Legacy 600, Learjet45). A commercial aircraft (Cessna CJ2) was used for 1 patient. Oxygen supplies were checked for the ECMO oxygenator and mechanical ventilation before transportation. Transport vehicles should also have an electrical supply sufficient for the ECMO pump and the heater. Suction systems, adequate lighting, and adequate space for the mobile ECMO team are also essential. The leader of the mobile ECMO team should also consider the safety of both the patient and mobile health officer, weather conditions, aircraft weight limitations, the potential cost of the aircraft, and valid passports for international flights.

RESULTS

Between 2016 and 2020, 6 patients supported with VA-ECMO for ACS were transported to our PICU by aircraft. One of the cases was female. The median age was 89 (14-204) months. The patients were previously healthy and not immunocompromised. All patients were not with a remarkable medical history, except for corrected transposition of great arteries (TGA) (case 2). On hospital admission, 4 patients suffered from dyspnea, and the others had palpitation and tachycardia. One of the patient’s heart rhythm was atrial flutter, and the other’s heart rhythm was refractory ventricular tachycardia. Therefore, they received antiarrhythmic therapy. In all cases, patients were with cardiac failure. There were fulminant myocarditis in 4, dilated cardiomyopathy in 1, and TGA and atrial flutter in 1 of the study cohort. Three patients were found to have severe myocarditis whose laboratory testing was positive for HIN1, coronavirus, and adenovirus. Venoarterial extracorporeal membrane oxygenation was set up for all patients. Three patients were transferred to our PICU due to the lack of an ECMO facility in the referring center. During all transport, 1 pediatric intensivist, 1 pediatric vascular surgeon, 1 perfusionist, and 1 nurse existed with their equipment (manual roller pump, vascular clamps, and portable electric generator). Three patients were assigned to attend our pediatric heart transplantation program.

Extracorporeal membrane oxygenation cannulation of 3 patients was done by our pediatric cardiovascular surgeons. Average 11 hours after patient admission, patients arrived at our PICU. The median distance of travel for patients who were transferred to our hospital was 618 (407-955) km. The median duration of patients’ transportation was 2.6 (2.5-3) hours. The route of the patients who underwent VA-ECMO and were transferred to our PICU by aircraft is given in Figure 1. We did not see any adverse events during transport. There was no mortality during transport.

While undergoing ECMO, 2 patients received plasma exchange, and 3 patients received continuous renal replacement treatment due to multiorgan dysfunction syndrome (MODS) and fluid overload. Extracorporeal membrane oxygenation cannulation...
was performed in 4 patients for myocarditis and 2 patients for heart failure. Extracorporeal cardiopulmonary resuscitation was applied to 3 patients with myocarditis. Venoarterial extracorporeal cardiopulmonary resuscitation was set up peripherically from the right carotid artery (CA) and internal jugular vein (IJV) in 3 patients and right femoral artery and femoral vein in 3 patients. Aircraft models used in the transfer of patients were Cessna CJ2, Learjet 45, and Legacy 600. The average ECMO duration was 8.8 (2-20) days. One patient received mechanical cardiac support with a left ventricular assist device because of a bridge to transplantation. Two patients died because of brain death after ECPR (cases 1 and 2), and 1 patient died from sepsis-related MODS (case 4). Femoral venoarterial ECMO was established at the 50th minute of CPR by the referring hospital personnel (case 4). The patient was transferred to our hospital on ECMO. Cases 1 and 2 were diagnosed with brain death by computed tomography angiography during follow-up. These 3 patients died after medical follow-up and 3 patients survived to hospital discharge. Characteristics of patients transported with ECMO support are given in Table 1.

DISCUSSION

Our mobile ECMO team at our institution has successfully transported 6 pediatric patients on VA-ECMO over 5 years. Critically ill patients have been transported by an aircraft provided by the Ministry of Health with trained staff for more than 8 years in our country. Our case series is the first report on ECLS aircraft transport of pediatric patients in Turkey.

Bartlett et al mentioned the first aircraft transport on ECMO. After that successful transport, several reports were published. Extracorporeal membrane oxygenation transport can be done by ground ambulance, helicopter, and fixed-wing aircraft. In ELSO guidelines, ground transport is recommended for a distance up to 400 km, helicopter transport for a distance of 650 km, and fixed-wing aircraft transport in any distance. Broman and Frenckner defined 3 steps of ECMO aircraft transport, including transport to the referring hospital with personnel and equipment, procedures at the referring hospital, and transport back to own facility or to another ECMO center. The final assessment of the patient, cannulation, initiation of ECMO at the referring hospital, and the ECMO transportation are achieved by the mobile ECMO team which Broman and Frenckner indicate as primary transport.

If the referring hospital has the opportunity of cannulation of ECMO for the hemodynamically unstable patient, this transportation is named secondary transport. In a report from Canada, pediatric patients required ECMO cannulated before...
Table 1. Characteristics of the study population, ECMO cannulation, transport strategies, and outcomes.

| Patients | Age          | Weight (kg) | BSA (m²) | Indication       | Initiation of VA-ECMO | Cannulation Configuration | Transport Distance (km) | Transport Duration (hours) | Aircraft Type | Fixed-Wing Versus Commercial | Complication | ECMO Days of Weaned Patients | Outcome        |
|----------|--------------|-------------|----------|------------------|------------------------|---------------------------|--------------------------|---------------------------|---------------|-------------------------------|--------------|-----------------------------|----------------|
| 1        | 22 months    | 10.8        | 0.49     | ECMPR            | Mobile ECMO team       | Right CA and IJV          | 720                      | 2.5                       | Legacy 600    | -                            | -            | -                           | -              |
| 2        | 14 years     | 44          | 1.36     | Myocarditis      | Referring hospital     | Right FA and FV           | 407                      | 3                         | Learjet 45     | -                            | -            | 2 days                      | Brain death    |
| 3        | 14 months    | 8.6         | 0.41     | Cardiac failure  | Mobile ECMO team       | Right CA and RJV          | 955                      | 2.5                       | Cessna CJ2     | (commercial)                 | -            | 7 days                      | Survived       |
| 4        | 17 years     | 57.2        | 1.6      | ECMPR            | Referring hospital     | Right FA and FV           | 505                      | 2.5                       | Cessna CJ2     | -                            | -            | On the 20th day of MODS      |                |
| 5        | 10 years     | 50          | 1.47     | ECMPR            | Mobile ECMO team       | Right CA and IJV          | 402                      | 2.5                       | Learjet 45     | -                            | -            | 8 days                      | Survived and bridged to LVAD |
| 6        | 12 years     | 45          | 1.38     | Cardiac failure  | Referring hospital     | Left FA and FV            | 720                      | 3                         | Learjet 45     | -                            | -            | 14 days                     | Survived       |

ECPR, extracorporal cardiopulmonary resuscitation; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; MODS, multiorgan dysfunction syndrome; LVAD, left ventricular assist device; CA, carotid artery; IJV, internal jugular vein; FA, femoral artery; FV, femoral vein.
parameters by observing clinically and monitoring arterial blood pressure, heart rate, and SpO₂, and also we followed ECMO parameters such as rotation per minute and ECMO blood flow (liter per minute).

Main limitations of the study are its retrospective nature and single-center data, but this report is the first and extraordinary implementation in pediatric critically ill child transportation. More case series and multi-center studies should be planned.

CONCLUSION

Interhospital ECMO decision, cannulation, initiation, and follow-up require expertise and a multidisciplinary approach. Extracorporeal membrane oxygenation transport also needs an experienced mobile ECMO team and appropriate logistics. Early referral of patients with ACS to the hospital may prevent delays and adverse outcomes. Even though there are limitations, ECMO aircraft transport could be achieved without adverse events. Extracorporeal membrane oxygenation should be established in critical patients if needed, and patients should be transported to appropriate medical centers with mobile ECMO teams.

Ethics Committee Approval: This study was approved by Ethics committee of Ankara University (Approval No: İ05-235-22, Date: 05.22).

Informed Consent: Written informed consent was obtained from all patients’ relatives or their representatives, where necessary, from their legal authority.

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