Survival outcomes after rescue extracorporeal cardiopulmonary resuscitation in pediatric patients with refractory cardiac arrest

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Supplemental material is available online.

Objectives: We report our experience with extracorporeal cardiopulmonary resuscitation with extracorporeal membrane oxygenation in children having cardiac arrest refractory to conventional cardiopulmonary resuscitation and explore predictors for favorable outcome (survival with grossly intact neurologic status).

Methods: We reviewed all patients who required extracorporeal cardiopulmonary resuscitation from 2000 to 2005. Multivariable regression analysis determined factors associated with favorable outcome and time-related survival.

Results: Eighty children, median age 150 days (range: 1 day–17.6 years), required venoarterial extracorporeal cardiopulmonary resuscitation. There were several categories of disease among the patients: postcardiotomy (n = 39), unoperated congenital heart disease (n = 17), cardiomyopathy (n = 12), respiratory failure (n = 9), or myocarditis (n = 3). Cannulation sites were neck (n = 45) or chest (n = 36). Median duration of extracorporeal membrane oxygenation was 4 days (range: 1–22). Extracorporeal membrane oxygenation was successfully discontinued in 42 (54%) patients: wean (n = 35), heart transplantation (n = 7). Survival till hospital discharge was 27 (34%) patients. Most common cause of death was ischemic brain injury (n = 17). Twenty-four (30%) patients had a favorable outcome. Median duration of cardiopulmonary resuscitation for patients with favorable versus unfavorable outcome was 46 minutes (range: 14–95; interquartile range: 29–55) versus 41 minutes (range: 19–110; interquartile range: 30–55), $P = .916$. According to the logistic regression model, none of the following factors was a significant predictor of favorable outcome: age, weight, sex, etiology (cardiac vs noncardiac), duration of cardiopulmonary resuscitation, cannulation site, timing, or location of extracorporeal membrane oxygenation institution.

Conclusions: Acceptable survival and neurologic outcomes (30%) can be achieved with extracorporeal cardiopulmonary resuscitation in children after prolonged cardiac arrest (up to 95 minutes) refractory to conventional resuscitation measures. Heart transplantation is often needed for successful extracorporeal cardiopulmonary resuscitation exit strategy. Lack of predictors of poor outcome support aggressive attempts to initiate extracorporeal cardiopulmonary resuscitation in all patients, followed by subsequent assessment of organ salvage.

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In-hospital cardiac arrest is associated with high mortality and subsequent morbidity in surviving children.[1-9] Additionally, increased duration of cardiopulmonary resuscitation (CPR) is associated with higher mortality and permanent central nervous system damage. After CPR duration lasting more than 30 minutes, survival with conventional CPR measures ranges between 0% and 5%.[1,2]

Abbreviations and Acronyms
CCU = critical care unit
CPR = cardiopulmonary resuscitation
ECMO = extracorporeal membrane oxygenation
ECPR = extracorporeal cardiopulmonary resuscitation
IQR = interquartile range
OHTX = orthotopic heart transplantation

Extracorporeal cardiopulmonary resuscitation (ECPR) is the rapid deployment of extracorporeal membrane oxygenation (ECMO) to provide immediate cardiovascular support for patients who have cardiac arrest unresponsive to conventional CPR measures.[2,9-18]

Several case series reported the use of ECPR in pediatric and adult cardiac patients, with a rate of survival to hospital discharge of 30% to 80%.[2,9-18] The use of ECPR in cardiac arrest for noncardiac medical conditions has been reported less frequently and has been associated with worse outcome.[2] Several series reported that mechanical assistance with ECMO in children having cardiac arrest refractory to conservative CPR measures is a significant factor for improved survival.[1-9] Survival may vary between different programs on the basis of patient selection and the capability to institute ECMO in a timely fashion. Since 2000, we have established a rapid resuscitation ECMO program at the Hospital for Sick Children in Toronto using a preassembled and preprimed ECMO circuit. The aim of this program is to re-establish cardiac output and organ perfusion and to prevent permanent end-organ injury while awaiting reversal of cardiac and other organ disease process or as a bridge to heart transplantation.

In this current series, we report our experience with ECPR over the past 5 years and explore predictors for favorable patient outcome, defined as hospital survival with grossly intact neurologic status.

Patients and Methods

Approval of this study was obtained from the Research Ethics Board at the Hospital for Sick Children in Toronto. From March 2000 to December 2005, 80 children less than 18 years of age required ECPR. Patients were included in the ECPR group if venoarterial ECMO was used as part of the initial active resuscitation from a cardiac arrest. Patients who were in hemodynamically unstable condition and placed on ECMO urgently without active cardiac arrest were not included in this study.

Patients were identified according to the institutional ECMO and Surgical Database. Clinical, operative, and outcome data were abstracted from the medical records. Risk factors available before the start of ECPR were analyzed.

ECMO Circuit and Equipment

A preassembled and preprimed ECMO circuit and trained personal are available in the critical care unit (CCU) at all times.

The circuit is composed of ¼-inch internal diameter polyvinyl chloride tubing with Carmeda (Medtronic, Minneapolis, Minn) heparin-bonded biocompatible surface coating. The total prime is approximately 400 mL. The main components are the Jostra Rotaflow centrifugal pump (Maquet, Hirrlingen, Germany) and Hilite 2400 LT oxygenator (Medos, Stolberg, Germany) (Figure E1). This system can support patients up to 20 kg and will provide temporary support for larger patients until a 3/8-inch circuit with an increased surface area oxygenator can be substituted. The circuit is primed with PlasmaLyte 148 (Baxter Corp, Toronto, Ontario, Canada), an unbuffered electrolyte solution, and is usable for 30 days. This safe limit has been determined by multiple periodic sterility testing of prime fluid with aerobic, anaerobic, and fungus cultures, and none of those cultures was positive up to 30 days.

Once ECPR is required, a predefined protocol is initiated. The circuit and all necessary ancillary equipment are brought to the bedside, creating a mini operating room setting in the CCU. A surgical table with sterile ECMO instrument tray, a single bundle of disposable and reusable equipment, a full cannulation cart with cannula size and flow guidelines, emergency albumin, cautery, and headlight are exclusively available to the rescue ECMO program and housed in the CCU.

All cannulations at our institution are performed by a staff cardiac surgeon or with a staff cardiac surgeon assisting. Cannulation site is dependent on the clinical situation. In postcardiotomy patients having postoperative cardiac arrest within the first week after surgery, direct aortic and atrial cannulation through the chest is usually done inasmuch as it provides the most expeditious means of instituting support while allowing the performance of effective open CPR. In patients who have cardiac arrest in settings other than the early postoperative period, neck cannulation is performed in our series of patients. Femoral cannulation can be considered as an alternative peripheral cannulation site in older children and adults.

When ECPR is requested, the blood bank is notified to prepare blood products. However, owing to time limitations, it is often necessary to initiate ECMO support with a clear prime. Heparin 1 U/mL of prime, sodium bicarbonate 15 mEq, and calcium chloride 250 mg are added to the prime before cannulation. Additionally, systemic heparin is administered at a dose of 50 U/kg body weight to maintain an activated clotting time of 180 to 200 seconds.

Once the patient's condition is stable on ECMO, the crystalloid volume is removed and packed red blood cells are added by a one-for-one syringe exchange transfusion process. Platelets and cryoprecipitate are given to correct the inherent coagulation deficiency. For children less than 1 year of age, an infusion of fresh frozen plasma is placed in the circuit at 20 mL/kg every 8 hours. The administration of blood products continues until transfusion targets are reached: hemoglobin 110 g/L, platelet count 100,000/mm^3, fibrinogen 2 g/L, and antithrombin 1 U/mL.

Rescue ECMO Team

The success of an ECPR program is dependent on the quick response of a team of specifically skilled and trained professionals. Individual roles and responsibilities have been identified so that the process can be expedited. A certified ECMO specialist and/or cardiovascular perfusionist are available in-house at all times. The

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