Weaning of extracorporeal membrane oxygenation using continuous hemodynamic transesophageal echocardiography

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Background: Venoarterial extracorporeal membrane oxygenation (VA ECMO) has been used for profound cardiogenic shock to bridge to decision, ventricular assist device(s) (VADs), or transplant. To assess ventricular function and volume status along with hemodynamics during ECMO weaning, we developed a standardized weaning protocol, guided by a miniaturized transesophageal echocardiography probe designed for continuous hemodynamic monitoring (hemodynamic transesophageal echocardiography [hTEE]). We reviewed our experience with this weaning protocol with hTEE guidance to assess if we could predict patient outcomes.

Methods: During the academic year of 2011, hTEE-guided ECMO weaning was performed in 21 patients on VA ECMO. Left and right ventricular function and volume status were assessed by continuous hTEE, while attempting to wean ECMO after a standardized protocol. The clinical outcomes, management, and positive predictive value of the device were investigated and analyzed for this cohort of patients.

Results: Of the 21 patients, 6 (29%) had left and right ventricular recovery and underwent optimal medical therapy or revascularization for underlying coronary artery disease; 7 (33%) had nonrecoverable left and right ventricular function; and 8 (38%) had right ventricular recovery without improvement of the left ventricular function. These 8 patients underwent left VAD placement; none subsequently developed profound right ventricular failure. The positive predictive value for ventricular recovery by hTEE was 100% using our standardized ECMO weaning protocol (95% confidence interval, 73%-100%).

Conclusions: The hTEE-guided ECMO weaning protocol accurately predicted the ability to wean ECMO to decision. This protocol can be applied by cardiac intensivists as a part of standard bedside intensive care unit assessment. (J Thorac Cardiovasc Surg 2013;146:1474-9)

Patients presenting with acute cardiogenic shock may require urgent placement of venoarterial extracorporeal membrane oxygenation (VA ECMO), before adequate assessment of either left or right ventricular function. VA ECMO at full flow provides near-total biventricular support and decompression of the heart, while allowing time to recover other end-organ function and to plan further medical or surgical management. Surgical management may involve implantable ventricular assist device(s) (VADs) or heart transplantation.

Determination of the left ventricular (LV) or right ventricular (RV) function before ECMO weaning is essential to predict biventricular or univentricular recovery and possible subsequent left VAD (LVAD) placement. Ideal candidates for LVAD placement would be those who have isolated LV failure with reasonably recovered RV function. Lack of recognition of significant coexisting RV dysfunction may significantly increase the postoperative morbidity and mortality in those patients transitioned to LVAD placement, requiring prolonged inotropic agents, biventricular device support, or extracorporeal support.

Because of the physiologic features of VA ECMO, the ECMO circuit creates negative pressure and drains venous blood from the right atrium, preventing determination of ventricular function from cardiac output or mixed venous oxygen analysis using a Swan-Ganz catheter (Edwards, Irvine, Calif). Therefore, intensivists and surgeons have been looking for alternative methods to assess left and right ventricular function to make clinical decisions regarding ECMO weaning and possible subsequent LVAD placement.

A relatively recent tool allowing the intensivist to directly assess both the contractility and filling status of both the RV and LV at the bedside in real-time is a miniaturized hemodynamic transesophageal echocardiography probe (hTEE; ImaCor, Garden City, NY). Unlike conventional transesophageal echocardiography (TEE) probes, which are 10 to 15 mm in diameter and require a TEE-certified cardiologist to introduce the probe to the patient, the

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Abbreviations and Acronyms

ECMO = extracorporeal membrane oxygenation
hTEE = hemodynamic transesophageal echocardiography
ICU = intensive care unit
LV = left ventricular
LVAD = left ventricular assist device
RV = right ventricular
TTE = transthoracic echocardiography
VA = venoarterial
VAD = ventricular assist device

hTEE probe is 5.5 mm in diameter, is disposable, and can remain indwelling for up to 72 hours for cardiac monitoring.[1] The probe can be placed by intensivists with hTEE training, providing clinically useful information.[2-4] The diagnostic yield of hTEE is comparable to that of conventional TEE regarding biventricular functions and volume status.[2,3,5,6] The safety of TEE was well established, with a reported incidence of major complications of 0.2% to 0.5% per insertion.[7-10] It is reasonable to expect the miniaturized hTEE probe to be even safer: we have seen no major complications in more than 200 hTEE examinations performed to date in our institution.

The small size and simplicity of the hTEE probe make it ideal for ECMO weaning because the entire weaning process may take several hours to observe hemodynamics after each adjustment of ECMO flow, volume status, and inotropic support. Motivated by TEE-guided weaning of cardiopulmonary bypass in the operating room,[11] timely and accurate clinical decisions can be made by the intensivist for weaning ECMO and subsequent treatment without additional personnel. We reviewed our experience using hTEE in patients on ECMO to assess the functional status of the LV and RV in weaning ECMO before proceeding to the next level of care.

METHODS

Patients

Between July 2011 and June 2012, 21 consecutive patients (Table 1) underwent centrally or peripherally cannulated VA ECMO support longer than 48 hours for multiorgan failure with *acute cardiogenic shock*, defined as a rapid decline of hemodynamics requiring multiple inotropes to achieve a cardiac index of 2 L/min per m^2. Once recovered, all patients underwent hTEE-guided ECMO weaning using our institutional hemodynamic weaning protocol. Patient demographics, including etiology of shock, are described in Table 1. This study was approved by the local internal review board.

ImaCor hTEE Probe

The hTEE probe is a disposable flexible probe with a diameter of approximately 5.5 mm, similar in size to an oral gastric tube, approved by the Food and Drug Administration for continuous cardiac function monitoring over a 72-hour period. The hTEE probe has 15 cm of penetration at 6.67 MHz (B-mode) and can obtain images revealing left and right ventricular function and volume status. A midesophageal 4-chamber view was obtained, on average, 42 to 45 cm from the incisors. A short-axis transgastric view was obtained by manipulating the flexible tip of the probe using the hand control. Echo parameters obtainable by hTEE include dimension, area, and ratio measurements in the transgastric short-axis view and the midesophageal 4-chamber view, in particular, left ventricular systolic and diastolic area and left ventricular fractional area change. However, these quantitative values were not routinely recorded in our practice. Instead, images obtained at hTEE were used directly for clinical decision making because these qualitative assessments are well established and validated in hemodynamic management.[4] All hTEE procedures were performed by cardiothoracic surgery intensivists, and none of them were TEE-trained cardiologists.

ECMO Weaning Trial Protocol

Before weaning ECMO, all patients met the criteria of being afebrile and euvolemic, with resolution of pulmonary edema on x-ray film, with adequate upper extremity arterial Pao_2 and saturation on 50% Fio_2 from both the ECMO and ventilator circuits, and all pre-ECMO end-organ dysfunction recovered to baseline.

For the weaning trial, anticoagulation was titrated to a partial thromboplastin time target of 60 to 70 seconds to avoid thrombotic complications while decreasing ECMO flow over the period of assessment. Standard vital parameters (arterial blood pressure, central venous pressure, heart rate, and rhythm) were monitored; no Swan-Ganz catheter was inserted during the weaning process. The hTEE probe was inserted transorally in all patients. Additional sedation was not required because of the small size of the probe. The weaning trial consisted of 4 stages:

Stage 1: Baseline LV and RV functions and volume status were assessed by hTEE on full-flow ECMO support.

Stage 2: After assessment of baseline data, ECMO flow was gradually decreased in steps of 0.5-L/min increments to the goal of half of the original flow (stage 2). Throughout the weaning protocol, LV and RV function and hemodynamic responses (heart rate and blood pressure) were monitored continuously to allow assessment of ventricular function and volume status. If, at any period in the weaning protocol, LV or RV distension occurred or significant hypotension was observed, the weaning trial was aborted and ECMO support was returned to full flow.

Stage 3: Volume challenges were done with 5% albumin (10 mL/kg) while ECMO flow was decreased to a minimum flow of 1.2 to 1.5 L/min. This volume challenge was necessary to achieve appropriate preload. Hemodynamic responses were monitored.

Stage 4: Inotropes (dobutamine and/or milrinone) were started, and the LV and RV functions and hemodynamics were observed for adequate response over 1 hour (a few hours for milrinone). If both LV and RV functions were recovered, the patient was considered for definitive ECMO removal. If LV dysfunction persisted, but RV function was recovered or improved, with inotropic support, the patient was considered for LVAD placement. If RV dysfunction persisted, but LV function was recovered, with inotropic support, the patient was considered for external right VAD placement. If biventricular dysfunction was observed, repeat assessment or total artificial heart placement was considered. If biventricular dysfunction was present and the patient was not a candidate for support because of another comorbid condition, end-of-life discussion was considered, because recovery is less likely.

After completion of the weaning trial, the ECMO flow was returned to full flow and the case was discussed with intensivists, surgeons, cardiologists, and family members for the timing of surgical intervention. A Swan-Ganz catheter was not used in any cases in the patients on ECMO because of a safety issue, such as migration of the catheter or introduction of the air to the ECMO system, and because of unreliability of the Swan-Ganz parameters because of the presence of suction applied on the venous cannula on the ECMO. The weaning processes are summarized in Table 2.

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