Two-Dimensional Strain Rate and Doppler Tissue Myocardial Velocities: Analysis by Echocardiography of Hemodynamic and Functional Changes of the Failed Left Ventricle during Different Degrees of Extracorporeal Life Support

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Background: To evaluate hemodynamic and functional changes of the failed left ventricle by Velocity Vector Imaging (VVI) and tissue Doppler, 22 patients with cardiogenic shock supported by extracorporeal life support (ECLS) were imaged during ECLS output variations inducing severe load manipulations.

Methods: The following data were acquired: (1) mean arterial pressure, aortic Doppler velocity-time integral, left ventricular end-diastolic volume, and mitral Doppler E wave; (2) tissue Doppler systolic (Sa) and early diastolic (Ea) velocities; and (3) systolic peak velocity (Sv), strain, and strain rate using VVI.

Results: Load variations were documented by a significant decrease in afterload (mean arterial pressure, −21%), an increase in preload (left ventricular end-diastolic volume, +12%; E, +46%; E/Ea ratio, +22%), and an increase in the velocity-time integral (+45%). VVI parameters increased (Sv, +36%; strain, +81%; and strain rate, +67%; $P < .05$), unlike tissue Doppler systolic velocities (+2%; P = NS). Whatever the ECLS flow, Sa was higher in patients who survived.

Conclusions: VVI parameters are not useful in characterizing the failed left ventricle with rapidly varying load conditions. Tissue Doppler systolic velocities appear to be load independent and thus could help in the management of ECLS patients. (J Am Soc Echocardiogr 2012;25:632-40.)

Keywords: Load dependence, Strain rate, Velocity Vector Imaging, Extracorporeal life support, Failed ventricle, Tissue Doppler velocities

Extracorporeal life support (ECLS) has been proposed for rescuing patients with refractory cardiogenic shock.[1-5] It has been successfully used as a bridge to myocardial recovery, cardiac transplantation, or the implantation of left ventricular (LV) assist devices in patients with various etiologies of overt cardiac failure.

A venous cannula inserted into the right atrium drains blood from the patient into the pumping mechanism of the ECLS circuit. The blood is oxygenated through a membrane oxygenator and perfused in the aorta by a centrifugal pump via a second cannula.[6] ECLS can be instituted centrally, through the right atrium and the ascending aorta, or peripherally, using the femoral vein and the femoral or axillary artery. During ECLS, right atrial drainage through the venous cannula partially or totally unloads the heart. The external device provides both circulatory and ventilatory functions and infuses oxygenated blood in the aorta; it ensures a contribution to the systemic output that may reach 100%, with output provided by the native heart of zero. By varying the flow of the ECLS centrifugal pump, load conditions are modified[6]: it decreases preload by draining blood directly from the right atrium and increases mean afterload by a steady flow infusion of oxygenated blood in the aorta.[7,8] ECLS is a model of load variation that simultaneously manipulates preload and afterload and is of physiologic interest. It is therefore suitable for assessing and validating LV parameters independent of load conditions.

The vast majority of LV functional parameters are sensitive to load conditions such as filling pressures and mean aortic pressure.[9-11] A recently introduced postprocessing of native echocardiographic sequences, Velocity Vector Imaging (VVI; Siemens Healthcare, Erlangen, Germany), might provide less sensitive parameters,[12,13] but this point is thus far not clearly established. The present study was designed to assess the influence of acute modifications of ECLS on the failed left ventricle by studying VVI echocardiographic

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Abbreviations

ECLS = Extracorporeal life support

IQR = Interquartile range

LV = Left ventricular

LVEDV = Left ventricular end-diastolic volume

LVEF = Left ventricular ejection fraction

VTI = Velocity-time integral

VVI = Velocity Vector Imaging

parameters by comparison with other two-dimensional and Doppler echocardiographic data. The secondary goal was to evaluate their relationship to patient outcomes.

METHODS

This study was conducted in accordance with the ethical standards of our hospital's committee for the protection of human subjects. Informed consent for demographic, physiologic, and hospital outcomes data analyses was not required, because this observational study did not modify existing diagnostic or therapeutic strategies.

Study

This prospective observational study included all patients who received ECLS at the Cardiology Institute of Hôpital La Pitié-Salpêtrière in Paris between February and August 2007. Venoarterial ECLS was initiated under the following circumstances: (1) acute refractory cardiogenic shock complicating acute myocardial infarction, end-stage dilated cardiomyopathy, or fulminant myocarditis; (2) post-cardiotomy cardiogenic shock; (3) immediate post-transplantation cardiac graft failure, with elevated pulmonary pressures and right ventricular or LV dysfunction or both; and (4) miscellaneous conditions (e.g., cardiotoxic drug overdose, acute cardiac allograft rejection, persistent cardiac arrest). Patients receiving venovenous ECLS or those with mitral prostheses or severe mitral valvulopathy were not included in the study.

The collected clinical parameters were age, sex, medical history, reason for admission to the intensive care unit, severity at admission assessed by the Simplified Acute Physiology Score II (range, 0–174),[14] type of ECLS (central or peripheral), ECLS duration, and outcome (weaning and survey at 1 month). Hemodynamic status was assessed daily by the invasive measurement of arterial pressure (systolic arterial pressure, diastolic arterial pressure, and mean arterial pressure) and heart rate.

The group of weaned patients was defined as those having the machine removed and not requiring further mechanical support in the following 30 days. Patients who could not be weaned from ECLS either died in the intensive care unit or were bridged to heart transplantation or to a ventricular assist device.

ECLS Management in the Intensive Care Unit

Patients were kept on ECLS for ≥48 to 72 hours. To determine the feasibility of permanent weaning, an ECLS weaning trial was undertaken in patients considered hemodynamically stable (i.e., baseline mean blood pressure > 60 mm Hg while receiving no or low-dose vasoactive agents and a pulsatile arterial waveform maintained for ≥24 hours, and when pulmonary blood oxygenation was not compromised). When a patient tolerated the full weaning trial and had an LV ejection fraction (LVEF) > 25% to 30% under minimal ECLS, ECLS removal was considered. If the patient remained stable after prolonged (15–20 min) complete-circuit clamping in the operating room, the machine was surgically removed and the mediastinum or femoral access surgically repaired. When ECLS weaning was deemed impossible, bridging to a ventricular assist device or transplantation was considered.

ECLS Weaning Trial and Load Manipulations

During the ECLS weaning trial, the patients were tested by means of acute stepwise decrease of support. The patients were exposed simultaneously to increased preload and decreased afterload. ECLS flow was decreased to 66%, 33%, and <10% of the initial output of the device for 10 min at each level. Between each level, ECLS flow was returned to 100% for 15 min. During this transient weaning, data were collected at different levels of ECLS: 100%, 66%, and 33% of the initial value of flow up to, if possible, and <10% of the initial output of the device. At each level, parameters were recorded after 5 min of the ECLS flow decrease.

If mean arterial pressure dropped significantly and constantly to <60 mm Hg during the trial, ECLS flow was returned to 100% of the initial flow, and the trial was stopped.

Population and Load Manipulations

Thirty-three patients were assessed. They were studied daily during 119 attempts at partial weaning. Twenty-two patients tolerated acute decreases to 66% of the initial support and were included in the final analysis. Eleven patients failed to endure <66% of the initial support and thus were excluded from the final analysis. All 22 patients who tolerated variations of ECLS output could be imaged. A total of 70 load conditions were stored and processed. The baseline characteristics of the 22 included patients are summarized in Table 1.

Echographic Examination and Conventional Doppler Echocardiographic Data

All echocardiographic examinations were performed daily at each level of ECLS flow by transthoracic echocardiography (Acuson Sequoia; Siemens Healthcare). The apical view was used to obtain standard four-chamber, three-chamber, and two-chamber long-axis views of the left ventricle. Two-dimensional black-and-white sequences corresponding to two beats were stored with a frame rate of 70 frames/sec in Digital Imaging and Communications in Medicine format for subsequent offline analysis. These sequences were used to measure LV end-diastolic volume (LVEDV) and to calculate LVEF using Simpson's rule. Transmitral early peak (E) and late diastolic velocities were recorded with pulsed Doppler in a four-chamber view. Spectral Doppler tissue imaging placed at the lateral and the septal mitral annulus measured early and late annular diastolic peak myocardial velocities. Then, pulsed Doppler was performed on the aortic valve to measure the aortic velocity-time integral (VTI).[15] Systolic velocity (Sa) and early diastolic (Ea) peak were obtained with the use of spectral Doppler tissue imaging at the mitral annular level (septal and lateral) (Figure 1). LV filling pressures and their variations were estimated with LVEDV and the E/Ea ratio.[16]

VVI Principles and Measurements

VVI is a recent technique for obtaining velocity, strain, and strain rate measurements. It analyzes motion by tracking speckles (natural acoustic markers) in the two dimensions of the ultrasonic image sequences. The displacement of each speckle is followed from one image to the next. This yields the systolic peak velocity (Sv), strain, and strain rate imaging. It has emerged as a quantitative technique to estimate myocardial function and contractility.[17] Strain is a dimensionless parameter representing deformation of an object, relative to its original shape, and is expressed as the percentage (or fractional) change