Use of Venovenous Extracorporeal Membrane Oxygenation and an Atrial Septostomy for Pulmonary and Right Ventricular Failure

Daniele Camboni, MD, Begum Akay, MD, Peter Sassalos, MD, John M. Toomasian, CCP/MS, Jonathan W. Haft, MD, Robert H. Bartlett, MD, and Keith E. Cook, PhD

Extracorporeal Life Support Laboratory, Department of Surgery, University of Michigan Medical School, Ann Arbor, Michigan

Background. **Right ventricular failure is a major contributor to morbidity and mortality on the lung transplant waiting list. This study was designed to evaluate the effectiveness of an atrial septostomy with venovenous extracorporeal membrane oxygenation (VV-ECMO) as a novel potential bridge to transplantation.**

Methods. **Adult sheep (58 ± 3 kg; n = 12) underwent a clamshell thoracotomy and instrumentation to measure all relevant pressures and cardiac output (CO). Sheep with tricuspid insufficiency (TI [n = 5]) and without tricuspid insufficiency (ØTI [n = 7]) were examined. After creation of a 1-cm atrial septal defect and initiating VV-ECMO, the pulmonary artery (PA) was banded to allow progressive reduction of pulmonary blood flow, and data were collected.**

Results. **The CO in both groups remained unchanged from baseline at all pulmonary blood flow conditions. With TI, the CO was 5.1 ± 1.2 L/min at baseline versus 5.1 ± 1.2 L/min with a fully occluded PA ($p = 0.99$). For ØTI, the CO was 4.5 ± 1.4 L/min at baseline versus 4.5 ± 1.2 L/min with no pulmonary blood flow ($p = 0.99$). Furthermore, CO was not affected by the presence of TI ($p = 0.76$). Mean right ventricular pressures were significantly lower in the TI group (TI = 20.2 ± 11 mm Hg versus ØTI = 29.9 ± 8.9 mm Hg; $p < 0.00001$). Right and left atrial mean arterial pressures were not different between both groups ($p > 0.5$). Lastly, VV-ECMO maintained normal blood gases, with mean O_2 saturations of 99% ± 4.1% in both groups.**

Conclusions. **Right to left atrial shunting of oxygenated blood with VV-ECMO is capable of maintaining normal systemic hemodynamics and normal arterial blood gases during high right ventricular afterload dysfunction.**

(Ann Thorac Surg 2011;91:144–9)

Early experimental studies in the mid 1960s and clinical observations in the mid 1980s have suggested that an interatrial shunt might be of benefit in the setting of severe primary pulmonary hypertension for the treatment of right ventricular failure [1, 2]. The presence of an atrial septal defect (ASD) would allow right to left shunting to increase systemic cardiac output (CO), resulting in an increase in systemic oxygen transport. Therefore, atrial septostomies are occasionally used to bridge patients to lung transplant. However, the role of an atrial septostomy in the treatment of pulmonary hypertension, especially when associated with hypoxemia, is still uncertain. The efficacy of atrial septostomies has been reported only in small series and case reports, and the success of the intervention is often unpredictable, mostly because of an untolerated hypoxia [2, 3]. These patients would require extracorporeal blood oxygenation, but there are no published data to support the compatibility of these two therapies. Recent advances in the technical aspects of extracorporeal membrane oxygenation (ECMO) have enabled patients to be supported with relative safety for several weeks, even facilitating extubation until a donor lung becomes available [4]. Therefore, the use of ECMO is expected to increase in the treatment of pulmonary failure in the future. For patients suffering from concomitant and refractory right ventricular failure, an atrial septostomy could be life saving.

This study was designed to test the feasibility of a combined pulmonary and ventricular support with an atrial septostomy and venovenous extracorporeal membrane oxygenation (VV-ECMO) as a novel potential bridge to lung transplantation. In addition, a significant portion of patients suffering from pulmonary hypertension develop some degree of tricuspid insufficiency (TI) due to right ventricular dilation and right ventricular hypertrophy [5]. Tricuspid insufficiency presents a low resistance path between the right ventricle and atrium and may increase right to left atrial shunting and better unload the right ventricle. Therefore, a secondary aim of this study was to measure the impact of TI on right to left atrial shunting.

Accepted for publication July 14, 2010.

Presented at the Poster Session of the Forty-sixth Annual Meeting of The Society of Thoracic Surgeons, Fort Lauderdale, FL, Jan 25–27, 2010.

Address correspondence to Dr Camboni, Extracorporeal Life Support Laboratory, Department of Surgery, University of Michigan, B560-B Medical Science Research Bldg II, 1150 W Medical Center Dr, Ann Arbor, MI 48109; e-mail: dcamboni@arcor.de.

Published by Elsevier Inc

0003-4975/$36.00
doi:10.1016/j.athoracsur.2010.07.036

Abbreviations and Acronyms

ASD = atrial septal defect
CO = cardiac output
CPB = cardiopulmonary bypass
ECMO = extracorporeal membrane oxygenation
LAP = left atrial pressure
ØTI = no tricuspid insufficiency
PA = pulmonary artery
PAP = pulmonary artery pressure
QPA = pulmonary artery flow rate
PVR = pulmonary vascular resistance
RAP = right atrial pressure
RVP = right ventricular pressure
TI = tricuspid insufficiency
VA = venoarterial
VV = venovenous

Material and Methods

The study was approved by the University of Michigan Committee on Use and Care of Animals and was conducted according to the University of Michigan policy according to the "Guide for the Care and Use of Laboratory Animals" (NIH publication 85-23, revised 1985).

Study Design

The hemodynamic and gas transfer effect of ASD and ECMO support was evaluated in two groups, one with tricuspid insufficiency (TI, n = 5) and one with no tricuspid insufficiency (ØTI, n = 7). Thus, the effect of tricuspid regurgitation on atrial shunting was also evaluated.

Surgical Instrumentation

Adult male sheep 59 ± 3 kg were anesthetized using a standard protocol, as previously described and used by our laboratory [6]. The ventilator (Narkomed 600; North American Draeger, Telford, PA) was set initially at a tidal volume of 10 mL/kg and a frequency of 12 to 15 breaths per minute to maintain the arterial pCO_2 between 35 and 45 mm Hg. Arterial and venous access was established by carotid and jugular catheterization using polyvinylchloride tubing (Abbott Critical Care Systems, North Chicago, IL). Both were connected to fluid coupled pressure transducers (Abbot Critical Care Systems) to monitor pressures, which were displayed continuously (Marquette Electronics, Milwaukee, WI).

A clamshell thoracotomy was performed, entering the chest cavity through the fourth intercostal space. After opening the pericardium, 16F angiocatheters (Becton-Dickinson Infusion Therapy Systems, Sandy, UT) were inserted into the right atrium, left atrium, and pulmonary artery and connected to fluid-coupled pressure transducers to measure right atrial pressure (RAP), left atrial pressure (LAP), and pulmonary artery pressure (PAP). A 6F micromanometer-tipped pressure probe (Millar Instruments, Houston, TX) was inserted into the conus region of the right ventricular free wall to measure right ventricular pressure (RVP). Ultrasonic perivascular flow probes were placed around the ascending aorta to measure continuous cardiac output (CO), and around the pulmonary artery (T206 Flowmeter; Transsonic Systems, Ithaca, NY) to measure PA flow rate (QPA). All pressure probes were inserted after creation of the ASD.

Cardiopulmonary Bypass/ECMO

The cardiopulmonary bypass (CPB) circuit consisted of a centrifugal pump (Biomedicus 520 D; Medtronic, Minneapolis, MN), a heater unit (ECMO-Temp; Zimmer, Dover, OH), oxygenator (Capiox SX; Terumo, Ann Arbor, MI), and 30F Tygon tubing and a venous reservoir (Minimax; Medtronic) with additional supply of a cardiotomy suction. The circuit was primed with 800 mL lactated Ringer's solution mixed with 50 mL 8.4% bicarbonate solution. Before initiating CPB, methylprednisolone (0.5 g intravenously [Pfizer, New York, NY]) was administered to reduce the inflammatory response to foreign surfaces of the circuit. Heparin (Baxter Healthcare, Deerfield, IL) was administrated at a dose of 100 U/kg, with the goal to reach and maintain activated clotting times above 400 s.

Normothermic CPB was established by bicaval venous cannulation (21F; Medtronic) with caval snares to isolate the right atrium. Reinfusion was realized by cannulation of the carotid artery (15F; Medtronic). Thereby, flows between 3.5 and 4 L/min were reached, with the goal of maintaining mean arterial pressure above 50 mm Hg under the aid of low doses of norepinephrine (Sicor, Irvine, CA), 0.05 to 0.1 $\mu g \cdot min^{-1} \cdot kg^{-1}$.

The interatrial septum was exposed through a standard right-sided atriotomy. Tricuspid insufficiency was created under direct vision by cutting four chordae tendinae of the posterior leaflet. The septal defect was built through the fossa ovalis, creating a defect of approximately 1 cm in diameter. Possible air embolism was prevented by the natural left to right atrial shunting, and by reestablishing venous return to the right atrium by loosing the snares around the venae cavae before closing the atriotomy.

After closing the atriotomy, the CPB circuit was converted into an ECMO circuit. The VV-ECMO was established with a modified Avalon dual lumen catheter (Avalon Laboratories, Rancho Dominguez, CA). The catheter was altered so that drainage from the superior vena cava was blocked, leaving only drainage from the inferior vena cava. The cannula was modified to reduce recirculation by blocking the drainage from the superior vena cava based on previous laboratory experience. In this setting, the excessive recirculation might be due regurgitant flow returning from the RV to the RA and the cavae. That might have lead to a diversion of the reinfusion stream into the superior vena cava during systole. The ECMO flow was kept between 2.5 L/min and 3.5 L/min as needed. The oxygenator was supplied with fraction of inspired oxygen (FiO_2) of 1.0 and a flow rate of 2 to 6 L/min according to arterial blood gases. With initiation of ECMO, the ventilator rate was changed to 4 to 8 breaths per minute.