ELSEVIER

The Journal of Heart and Lung Transplantation

http://www.jhltonline.org

ORIGINAL PRE-CLINICAL SCIENCE

Right ventricular unloading and respiratory support with a wearable artificial pump-lung in an ovine model

Yang Liu, PhD, MD,[a,b] Pablo G. Sanchez, PhD, MD,[a] Xufeng Wei, PhD, MD,[a,b] Tieluo Li, MD,[a] Amelia C. Watkins, MD,[a] Shu-ying Li, MD,[a] Bartley P. Griffith, MD,[a] and Zhongjun J. Wu, PhD[a,b]

From the [a]Department of Surgery, University of Maryland School of Medicine, Baltimore, Maryland, USA; and the [b]Department of Cardiac Surgery, Xijing Hospital, Fourth Military Medical University, Xi'an, China.

KEYWORDS:
right heart unloading;
respiratory support;
artificial pump lung;
heart failure;
mechanical circulatory support;
extracorporeal membrane oxygenation (ECMO)

BACKGROUND: Device availability of mechanical circulatory or respiratory support to the right heart has been limited. The purpose of this study was to investigate the effect of right heart unloading and respiratory support with a wearable integrated artificial pump-lung (APL).

METHODS: The APL device was placed surgically between the right atrium and pulmonary artery in 7 sheep. Anti-coagulation was performed with heparin infusion. The device's ability to unload the right ventricle (RV) was investigated by echocardiograms and right heart catheterization at different bypass flow rates. Hemodynamics and echocardiographic data were evaluated. APL flow and gas transfer rates were also measured at different device speeds.

RESULTS: Hemodynamics remained stable during APL support. There was no significant change in systemic blood pressure and cardiac index. Central venous pressure, RV pressure, RV end-diastolic dimension and RV ejection fraction were significantly decreased when APL device flow rate approached 2 liters/min. Linear regression showed significant correlative trends between the hemodynamic and cardiac indices and device speed. The oxygen transfer rate increased with device speed. The oxygen saturation from the APL outlet was fully saturated (>95%) during support. The impact of APL support on blood elements (plasma free hemoglobin and platelet activation) was minimal.

CONCLUSIONS: APL device support significantly unloaded the RV with increasing device speed. The device also provided stable hemodynamics and respiratory support in terms of blood flow and oxygen transfer. The right heart unloading performance of this wearable device needs to be evaluated further in an animal model of right heart failure with long-term support.

J Heart Lung Transplant ▮▮▮▮;▮:▮▮▮–▮▮▮

Mechanical circulatory support (MCS) therapy has evolved into a standard therapy for patients with advanced heart failure (HF), not only as a bridge to myocardial recovery or cardiac transplantation but also as destination therapy.[1–3] The number of patients receiving MCS therapy has quadrupled over the last 5 years. The majority of MCS devices have been specifically designed as left ventricular assist devices (LVADs) for left heart failure (LHF). MCS devices for appropriate right heart support are limited. Although right heart failure (RHF) is not as frequent as LHF, it occurs commonly, and may be complicated by left heart dysfunction or primary pulmonary hypertension,

Reprint requests: Zhongjun J. Wu, PhD, Artificial Organs Laboratory, Department of Surgery, University of Maryland School of Medicine, MSTF-436, 10 South Pine Street, Baltimore, MD 21201. Telephone: 410-706-7715. Fax: 410-706-0311.

E-mail address: zwu@smail.umaryland.edu

1053-2498$ - see front matter
http://dx.doi.org/10.1016/j.healun.2014.02.026

usually presenting with overloaded congestive heart failure.[4,5] RHF also occurs in 20% to 50% of LVAD patients and negatively impacts their morbidity and mortality.[6,7] Despite medical advances, the medical therapy does not work well in end-stage RHF. Heart transplantation or heart and lung transplantation are optimal choices for end-stage RHF patients, yet they are limited by the shortage of organ donors.[8,9] MCS devices designed for the left heart and extracorporeal membrane oxygenation (ECMO) systems, such as pulsatile and continuous VADs, have been used occasionally to relieve RHF symptoms.[10–13] These approaches have their own shortcomings, however, including no respiratory support function in the VADs and poor long-term biocompatibility, low efficiency of unloading, and complex and bulky components in the ECMO systems.

Over the last decade, ambulatory respiratory/cardiopulmonary support and percutaneous right heart support have emerged and gained acceptance among physicians and surgeons.[14,15] An ultra-compact integrated artificial pump-lung (APL) is currently being developed for ambulatory respiratory or cardiopulmonary support.[16] The APL consists of a uniquely configured hollow-fiber membrane (HFM) bundle integrated with a magnetically levitated centrifugal impeller pump. The APL is comparable in size to a 12-ounce soda can. It can function either as a respiratory support device or partial cardiopulmonary support device, with maximal flexibility of application in the broad spectrum of heart/lung diseases. The APL device not only supplies cardiac support but also has a gas-exchange function. Thus, the APL could be the best alternative for RHF. The objective of this study was to evaluate the effect of right ventricular unloading and respiratory support function of the APL device in an acute ovine model.

Methods

Device description

The APL device is 117 mm in length and 89 mm in diameter. Its priming volume is 115 ml. The combined weight of the APL and motor/controller unit is only 0.54 kg. It was designed to be a fully integrated pump-lung for respiratory and heart failure support. The APL's design combines a magnetically levitated centrifugal pump and a hollow-fiber membrane bundle to form one single compact system capable of both pumping and oxygenation. The pumping function of the APL was designed based on a continuous-flow, centrifugal-type rotary blood pump supported by magnetically levitated bearingless impeller/motor technology. The oxygenation component is made of microporous HFMs. To achieve the most effective use of the fiber membranes, maximum gas exchange, and elimination of deleterious flow stagnancy, a cylindrical HFM bundle with a unique circumferential–radial uniform outside-in flow path design is employed. Figure 1A shows the sectional view of the flow path inside the APL. Venous blood is drawn from the patient into the APL pump chamber from a central cylindrical tube through a drainage cannula. Driven by a magnetically levitated rotating centrifugal pump impeller, the blood is propelled through the diffuser section and flows toward the space between the outer housing and the polymethylpentene HFM (Oxyplus; Membrana, Wuppertal, Germany) bundle. While the blood passes through the HFM bundle, the oxygen is transferred from the fiber lumen to the blood and the carbon dioxide is removed from the blood. The oxygenated blood is collected at the space between the HFM bundle and the center tube and returned back to the patient through

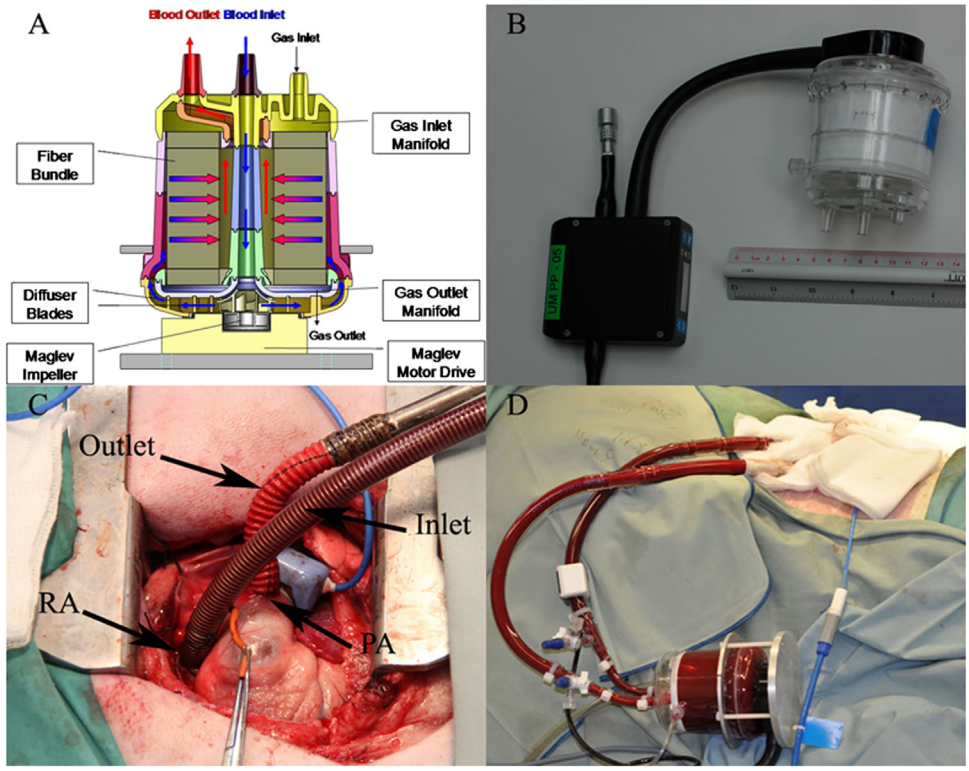

Figure 1 (A) Cross-sectional view of the artificial pump-lung and flow path. (B) Description of the APL device. (C) Surgical implantation. (D) Total circulation of the APL device. PA, pulmonary artery; RA, right atrium.